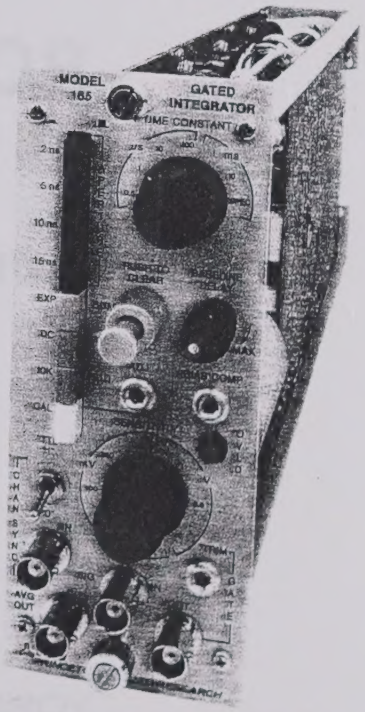
MODEL 165
GATED INTEGRATOR

READ SAFETY NOTICE
ON PAGE I-1 BEFORE
OPERATING INSTRUMENT



OPERATING AND SERVICE MANUAL

EG&G
PRINCETON APPLIED RESEARCH

MODEL 165
GATED INTEGRATOR

OPERATING AND SERVICE MANUAL

EG&G PRINCETON APPLIED RESEARCH

M165; 7/82; 500; MIC

Copyright © 1982 EG&G PRINCETON APPLIED RESEARCH

Printed in U.S.A.

SHOULD YOUR EQUIPMENT REQUIRE SERVICE

A. Contact the factory (609/452-2111) or your local factory representative to discuss the problem. In many cases it will be possible to expedite servicing by localizing the problem to a particular plug-in circuit board.

B. If it is necessary to send any equipment back to the factory, we need the following information.

(1) Model number and serial number.

(2) Your name (instrument user).

(3) Your address.

(4) Address to which instrument should be returned.

(5) Your telephone number and extension.

(6) Symptoms (in detail, including control settings).

(7) Your purchase order number for repair charges (does not apply to repairs in warranty).

(8) Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation).

C. U.S. CUSTOMERS—Ship the equipment being returned to:

EG&G PRINCETON APPLIED RESEARCH
7 Roszel Road
(Off Alexander Road, East of Route 1)
Princeton, New Jersey

D. CUSTOMERS OUTSIDE OF U.S.A.—To avoid delay in customs clearance of equipment being returned, please contact the factory or the nearest factory distributor for complete shipping information.

E. Address correspondence to:

EG&G PRINCETON APPLIED RESEARCH
P. O. Box 2565
Princeton, NJ 08540

Phone: 609/452-2111
TELEX: 84 3409

WARRANTY

EG&G PRINCETON APPLIED RESEARCH warrants each instrument of its manufacture to be free from defects in material and workmanship. Obligations under this Warranty shall be limited to replacing, repairing or giving credit for the purchase price, at our option, of any instrument returned, freight prepaid, to our factory within ONE year of delivery to the original purchaser, provided prior authorization for such return has been given by our authorized representative.

This Warranty shall not apply to any instrument which our inspection shall disclose to our satisfaction, has become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation or other causes beyond our control. Instruments manufactured by others, and included in or supplied with our equipment, are not covered by this Warranty but carry the original manufacturer's warranty which is extended to our customers and may be more restrictive. Certain subassemblies, accessories or components may be specifically excluded from this Warranty, in which case such exclusions are listed in the Instruction Manual supplied with each instrument.

We reserve the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION HEREIN. THIS WARRANTY IS IN LIEU OF, AND EXCLUDES ANY AND ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESSED, IMPLIED OR STATUTORY, INCLUDING MERCHANTABILITY AND FITNESS, AS WELL AS ANY AND ALL OTHER OBLIGATIONS OR LIABILITIES OF EG&G PRINCETON APPLIED RESEARCH, INCLUDING, BUT NOT LIMITED TO, SPECIAL OR CONSEQUENTIAL DAMAGES. NO PERSON, FIRM OR CORPORATION IS AUTHORIZED TO ASSUME FOR EG&G PRINCETON APPLIED RESEARCH ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED FOR HEREIN EXCEPT IN WRITING DULY EXECUTED BY AN OFFICER OF EG&G PRINCETON APPLIED RESEARCH.

TABLE OF CONTENTS

Section			Page
I	SAFETY NOTICE		I-1
	1.1	Introduction	I-1
	1.2	Inspection	I-1
	1.3	Safety Mechanism	I-1
	1.4	Defects and Abnormal Stresses	I-1
II	CHARACTERISTICS		II-1
	2.1	General	II-1
	2.2	Specifications	II-1
III	INITIAL CHECKS		III-1
	3.1	Introduction	III-1
	3.2	Equipment Needed	III-1
	3.3	Preliminary Steps	III-1
	3.4	Module Checks	III-1
		3.4A Checks in the External-Trigger Mode	III-1
		3.4B Internal-Trigger Mode Checks	III-3
		3.4C Hold Checks	III-4
	3.5	Dual-Channel Operation	III-4
IV	OPERATING INSTRUCTIONS		IV-1
	4.1	Controls, Connectors, and Indicators	IV-1
	4.2	Input Signal Processing	IV-3
		4.2A Input Impedance Selection	IV-3
		4.2B Input Coupling	IV-3
		4.2C Input Voltage Limits	IV-3
		4.2D Zeroing and Calibration	IV-4
		4.2E Synchronization	IV-4
		4.2F Exponential vs Summation Averaging	IV-5
		4.2G Time Constant and Aperture Duration	IV-7
		4.2H Resolution, Measurement Time, and SNIR as a Function of Aperture Duration	IV-9
		4.2I Droop	IV-10
		4.2J Summary: ADR, AD, TC, P_{MAX}, MST	IV-11
		4.2K Baseline Sampling	IV-16
		4.2L Channel Sync. (Alternate Channel Triggering)	IV-17
		4.2M Matching the Digital-Storage Option to the Model 165	IV-17
V	ALIGNMENT		V-1
	5.1	Introduction	V-1
	5.2	Equipment Required	V-1
	5.3	Preliminary Steps	V-1
	5.4	Power-Supply Adjustments	V-1
	5.5	High-Impedance-Buffer Adjustment	V-1
	5.6	Wide-Band Amplifier	V-2
	5.7	A.T. Gate Generator	V-2
	5.8	Sample-and-Hold Circuit Adjustment	V-3
	5.9	Signal-Channel Integrator	V-4
	5.10	Baseline-Channel Integrator	V-5
	5.11	Baseline/Signal-Channel Adjustments	V-5
	5.12	Feedback Amplifier, Zero Adjustment	V-5
	5.13	Output Amplifier	V-5
	5.14	Charge-Pump Compensation	V-6
	5.15	Fine-Loop Zero	V-7
	5.16	Sampling-Gate Compensation	V-8
	5.17	Store-Gate Compensation	V-8

VI TROUBLESHOOTING VI-1
6.1 Introduction VI-1
6.2 Block Diagram Discussion VI-1
6.2A General Run-Through VI-1
6.2B Trigger Circuits VI-2
6.2C Summation Mode VI-5
6.2D Store INH VI-6
6.3 Troubleshooting Procedure VI-6
6.3A Introduction VI-6
6.3B Equipment Required VI-6
6.3C Preliminary Steps VI-6
6.3D Power-Supply Checks VI-6
6.3E Isolation of Faults VI-6

VII SCHEMATICS, Table of VII-1

FIGURES

Number **Page**

II-1 Mounting Terminals for "Special" TC Capacitors II-2
IV-1 Model 165 Gated Integrator IV-1
IV-2 Model 165 Input Circuits IV-3
IV-3 Exponential Averaging Weighting Factor as a Function of – t/OTC IV-6
IV-4 Output Response as a Function of Analysis Time for Both Exponential and Summation Averaging IV-6
IV-5 Model 165: N as a Function of Aperture Duration and Set Time Constant IV-8
IV-6 P_{MAX} Calculations IV-11
IV-7 P_{MAX} as a Function of TC and AD IV-12
IV-8 Important Parameters of Boxcar Operation IV-13
IV-9 'Scope Portrayal of Improper Control Settings IV-15
IV-10 Analysis of Figure IV-9 (5B) IV-16
IV-11 Channel-Sync Timing IV-17
IV-12 Digital-Storage Zero and Gain Adjustments IV-18
V-1 A.T. Gate Generator/Logic Board V-2
V-2 Sampling Board V-3
V-3 A.T. Gate Generator Pulse Alignment V-3
V-4 Integrator Board V-4
V-5 Delay-Range-Frame Timing Diagrams V-6
V-6 Charge-Pump Compensation: Signal-Channel Adjustments V-7
V-7 Sampling Board, Side View V-7
V-8 Store-Gate Compensation Adjustment V-9
VI-1 Block Diagram VI-3
VI-2 Model 165 Timing VI-4
VI-3 Sampling Gate Test Set-Up VI-7

TABLE

Number **Page**

IV-1 Integrator Capacitor vs Time Constant IV-10

Digitized by the Internet Archive
in 2025

https://archive.org/details/manualsplus_06095

HOW TO USE THIS MANUAL

This manual covers operation of only the Model 165 controls. Since the Model 165 must be operated in the Model 162 mainframe, it is essential that the user fully understand operation of the mainframe. In this manual, reference to the mainframe controls is made only as necessary to discuss the Model 165 properly. Consequently, this manual cannot stand alone as an operating guide to the Model 165; the Model 162 manual is equally important—particularly in regard to those discussions that relate to the mainframe operating parameters and their interactions with the plug-in modules. Those sections in the Model 162 manual that describe the Model 163 Sampled Integrator and the Model 164 Gated Integrator may be ignored.

SECTION I
SAFETY NOTICE
(Read before operating instrument)

1.1 INTRODUCTION

The apparatus to which this instruction manual applies has been supplied in a safe condition. This manual contains some information and warnings which have to be followed by the user to ensure safe operation and to retain the apparatus in a safe condition.

The described apparatus has been designed for indoor use. It may occasionally be subjected to temperatures between +5°C and −10°C without degradation of its safety.

1.2 INSPECTION

Newly received apparatus should be inspected for shipping damage. If any is noted, notify EG&G PARC and file a claim with the carrier.

WARNING!

THE PROTECTIVE GROUNDING COULD BE RENDERED INEFFECTIVE IN DAMAGED APPARATUS. DAMAGED APPARATUS SHOULD NOT BE OPERATED UNTIL ITS SAFETY HAS BEEN VERIFIED BY QUALIFIED SERVICING PERSONNEL. DAMAGED APPARATUS WAITING FOR SAFETY VERIFICATION SHOULD BE TAGGED TO INDICATE TO A POTENTIAL USER THAT IT MAY BE UNSAFE AND THAT IT SHOULD NOT BE OPERATED.

1.3 SAFETY MECHANISM

As defined in IEC Publication 348 (*Safety Requirements for Electronic Measuring Apparatus*), this is Class I apparatus; that is, this apparatus depends on connection to a protective conductor to earth ground for equipment and operator safety. Before any other connection is made to the apparatus, the protective earth ground shall be connected to a protective conductor. The protective connection is made via the mating connector to the Model 162, and from there back through the earth ground prong of the Model 162's power cord plug. The power cord plug of the Model 162 shall only be inserted in a socket outlet provided with the required earth ground contact. The protective action must not be negated by the use of an extension cord without a protective conductor. Similarly, the Model 165 should not be operated remotely from the Model 162 if the extender cable does not have all the ground connections normally existing between the Model 165 and the Model 162.

WARNING!

ANY INTERRUPTION OF THE PROTECTIVE CONDUCTOR INSIDE OR OUTSIDE THE APPARATUS OR DISCONNECTION OF THE PROTECTIVE EARTH TERMINAL MAY MAKE THE APPARATUS DANGEROUS. INTENTIONAL INTERRUPTION IS PROHIBITED.

1.4 DEFECTS AND ABNORMAL STRESSES

Whenever it is likely that the protection provided by the connection to earth ground has been impaired, the apparatus shall be made inoperative and secured against any unintended operation. The protection is likely to be impaired if, for example, the apparatus:

(1) Shows visible damage;

(2) Fails to perform the intended measurements;

(3) Has been subjected to prolonged storage under unfavorable conditions;

(4) Has been subjected to severe transport stresses.

Such apparatus should not be used until its safety has been verified by qualified servicing personnel.

SECTION II
CHARACTERISTICS

2.1 GENERAL

The Model 165 Gated Integrator is a plug-in module for the Model 162 Boxcar Averager that significantly extends the usefulness and scope of applications of the M162 system. (The Model 162 can accept either one or two modules of Models 163, 164 or 165—mixed or paired.) The M165 features include: variable aperture durations as short as 2 ns; two decades of variable signal gain; the ability to accept high or low signal-repetition rates; and a unique dual-channel sampling mode (Alternate-Channel Triggering), which allows narrow-aperture analysis of a pair of widely spaced pulses with two plug-in modules.

Four pushbutton switches on the M165 front panel provide selection of aperture durations of 2, 5, 10 and 15 ns. When all pushbuttons are released, the Aperture-Duration switch on the mainframe front panel is enabled—providing continuously variable aperture durations from 20 ns to 5 ms. (Wider settings, up to 50 ms, are possible with a simple modification.)

Dual-channel operation, with a M165 in one channel and a M164 or M165 in the second channel, provides great flexibility in signal processing. For example, aperture durations for each channel now can be set independently—over a wide range of values.

Full-scale signal-sensitivity is adjustable in seven steps, from ± 50 mV to ± 5 V, to accommodate a wide range of input-signal and noise levels. A front-panel gate-width trim control simplifies module matching for dual-channel operation. Averaging time constants are selectable from 0.5 μs to 10 ms, providing latitude for trading off measurement time against the desired signal-to-noise improvement. For example, the shorter time-constant settings of the M165 allow substantial reductions in experimental time when modest signal-averaging suffices, or when the number of stimuli applied to a fragile test sample must be limited.

The M165 also features a built-in Baseline Sampling mode, in which both the signal and the baseline are sampled. Internal circuitry then automatically subtracts the averaged baseline from the averaged signal, to obtain an output free from drift and offset.

Pushbutton switches provide internal calibration checks, ac/dc coupling selection, the choice of 50 Ω or 10 kΩ input resistance, and either exponential or linear-summation averaging.

Sampled-and-held data are available, at the AVG OUT BNC connector, for connection to peripheral devices such as computers.

2.2 SPECIFICATIONS

Input Characteristics:

(1) SENSITIVITY (full scale): ± 50 mV to ± 5 V in a 1-2.5-5 sequence. The accuracy of voltage attenuation, range-to-range, relative to the 5 V range, is as follows: ± 2%, dc to 100 MHz; ± 3%, 100 MHz to 250 MHz. A user-adjustable Gain Trim permits gain variation of approximately ± 5%, FS.

(2) MAXIMUM SAFE INPUT: ± 5 V rms.

CAUTION: Protective diodes are automatically inserted in the input circuitry when the 10 kΩ input is in use. Such diodes tend to minimize the effect of an over-voltage applied to the input. There are, however, no protective diodes in the 50 Ω input circuit. Consequently, applied voltages greater than ± 5 V rms may damage the low-impedance input circuitry.

THE DANGER IS PARTICULARLY ACUTE WHEN USING THE INPUT RESISTANCE OF THE MODEL 165 AS THE LOAD RESISTOR OF A PHOTOMULTIPLIER, ESPECIALLY IF THE CABLE TO THE MODEL 165 INPUT IS DISCONNECTED AND THEN LATER RECONNECTED. When the cable is disconnected, the output of the photomultiplier rides up to the full supply voltage, possibly a few kilovolts. When the cable is reconnected, this full voltage is applied to the Model 165 input, damaging the input circuit before the voltage drops to the nominal "near-ground" potential.

(3) INPUT IMPEDANCE: 50 Ω (VSWR 1:1.2, max.), or 10 kΩ shunted by 25 pF, switch selectable.

(4) INPUT COUPLING: ac or dc, switch selectable. With ac coupling the high-pass − 3 dB point is nominally as follows:

(a) 50 Ω: 3.2 kHz

(b) 10 kΩ: 16 Hz.

Below these frequencies, the response is attenuated at a rate of 6 dB/octave (20 dB/decade).

(5) DYNAMIC RESERVE: The M165 can accept wide-band input-noise levels up to five times full scale, peak-to-peak. Higher input-noise

levels may cause non-linear operation. The OVERLOAD indicator will light when the coherent-plus-non-coherent input signal exceeds five times full scale.

Aperture Duration: 2, 5, 10 or 15 ns, pushbutton selectable. Pushbuttons override mainframe aperture-duration selection for that channel; when all pushbuttons are released, mainframe aperture-duration selection is enabled.

Aperture Duration Trim Range: ± 10%, front-panel screwdriver-adjustable. (Not applicable to Aperture Durations set by the 2, 5, 10 or 15 ns pushbuttons.)

Sampling Noise:

Aperture Duration	Pk-Pk Sampling Noise*
2 ns, 5 ns	1.5 mV
10 ns, 15 ns	1.0 mV
Over 15 ns but less than 1 μs	750 μV
1 μs and over	250 μV

*Referred to input.

Hold Time: Hold time is defined in terms of the maximum trigger period that will result in no more than 1% of full-scale error. For the M165, the maximum trigger period is computed as follows:

$P_{MAX} = 5 \times 10^{10} C \times (1 - e^{-AD/\tau})$, where
P_{MAX} is the maximum trigger period in seconds;
C is the value, in farads, of the integrating capacitor in the M165;
AD is the Aperture Duration, in seconds; and
τ is either the Time Constant set on the M165, or—for Aperture Durations shorter than 1 μs—the Apparent Time Constant.

Refer to Figure IV-5 in Subsection 4.2I for computations of Apparent Time Constant, and to Table IV-1 for values of the integrator capacitor.

With a time constant of 10 ms and an aperture duration of 5 ms, the trigger period may be as large as (approximately) 2×10^4 s. With a time constant of 0.5 μs and an aperture duration of 2 ns, the maximum trigger period will be approximately 0.3 s.

Maximum Trigger Repetition Rate
For Aperture Durations of 2 ns through 15 ns: 10 kHz. (Trigger hold-off circuitry prevents triggering faster than 10 kHz.)
For Aperture Durations of 20 ns through 50 ms: 5 MHz. (The mainframe will trigger as fast as 5 MHz, but the maximum usable trigger repetition rate is dependent upon the Aperture-Delay Range: the mainframe will prevent more than one trigger per ADR.)

Signal-to-Noise Improvement Ratio
(1) SUMMATION (LINEAR AVERAGING): Varies as the square root of the number of repetitions of the applied signal. Model 165 Time Constant and Aperture Duration have no effect on signal-to-noise improvement.

(2) EXPONENTIAL AVERAGING: The signal-to-noise improvement ratio varies approximately as $(2TC/AD)^{1/2}$, where TC is the M165 Time-Constant switch setting in seconds, AD is the Aperture Duration in seconds, "white" noise is assumed, and where the measurement has continued for a minimum of five times the observed time constant.* The observed time constant is defined as $TC/T_{rr} \times AD)$, where T_{rr} is the trigger repetition rate in repetitions per second, and the other symbols are as previously defined. Note, however, that for time-constant settings shorter than 1 μs, the observed time constant (OTC) must be replaced by the apparent time constant (ATC), as detailed in Subsection 4.2G.

*NOTE: When noise is mentioned in this manual it is assumed to be "white" (constant spectral power density independent of the frequency), but band-limited from dc to a maximum frequency equivalent to 1/2AD

Time Constant: Front-panel switch allows choice of six time constants from 0.5 μs to 10 ms, plus a SPECIAL position, in which a time constant intermediate to, or longer than, those provided can be set by a user-installed internal capacitor. The value for the latter may be computed as follows:

$$C = \frac{\tau}{10^4}$$

where
C is the required capacitance in farads, and
τ is the desired time constant in seconds (see Figure II-1).

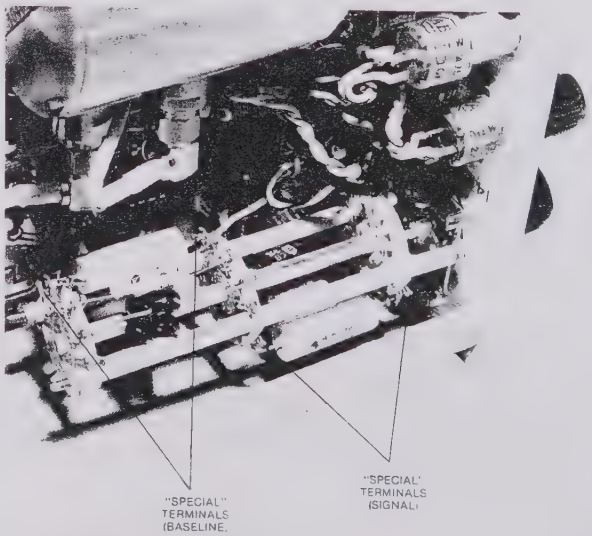


Figure II-1. MOUNTING TERMINALS FOR "SPECIAL" TC CAPACITORS (IDENTICAL VALUES SHOULD BE USED FOR THE "SIGNAL" AND "BASELINE" CHANNELS)

Linearity: When system has been zeroed and gain-calibrated, the deviation of the output from FS × IN, where FS = full scale and IN = input expressed as a fraction of full scale, is typically ±0.1% of full scale. This specification is degraded at low duty factors.

Coherent Pickup: ≤1 mV, pk-pk, referred to the input.

Zero: Zeroing provided by front-panel control with nominal range of ±45% of full scale for signal and baseline modes. Range not necessarily symmetrical with respect to "0". Unit must be triggering for proper zero adjustment.

Clear: Pushbutton control shorts out the integrator, allowing it to be cleared instantly. TTL signal applied to mainframe allows remote clearing.

Baseline Sampling

(1) FREQUENCY: Every other trigger repetition; signal-sampling cycles and baseline-sampling cycles alternate.

(2) BASELINE-SAMPLE DURATION: Same as for signal-sample aperture duration.

(3) BASELINE-SAMPLING AVERAGING: Same as for signal-sampling averaging.

(4) M165 OUTPUT: Difference between average of signal sample and average of baseline sample. With Baseline Sampling inoperative, output is the difference between average of signal sample and ground.

(5) BASELINE-SAMPLE POSITION: Set by M165 front-panel uncalibrated control; allows baseline sample to be positioned over the range of about 5% to 100% of the Aperture Delay Range. (Control also turns baseline-sampling function on or off.)

Outputs

(1) SIGNAL MONITOR OUTPUT: Inverted output (∓10 V, FS with respect to input), available at front-panel BNC connector (AVG OUT). Same signal is routed internally to M162 circuitry for additional processing.

(2) GATE OUT: Positive-going pulse provided for each gate opening. Pulses have an amplitude of nominally 150 mV and rest on a baseline of +250 mV (50-ohm termination of the Gate-Out BNC connector assumed). The baseline-sampling gate pulses are identifiable by a positive spike of approximately 75 mV on their leading edges. Pulse width depends on the selected Aperture Duration (pulses equal Aperture Duration down to approximately 50 ns). For Aperture Durations selected with M165 pushbuttons, 100-ns marker pulse is provided for Signal Channel and 200-ns pulse is provided for Baseline Channel. Leading edge of the marker pulse is coincident with the gate opening.

Gain Calibration: 5 V ±1% internally derived voltage available for calibration when CAL pushbutton is depressed.

General

(1) SIZE: 6.7 cm W × 16.8 cm H × 38.1 cm D (2-5/8" W × 6-5/8" H × 15" D).

(2) WEIGHT: 1.8 kg (4 lbs).

(3) POWER REQUIREMENTS: Power is supplied by M162 mainframe.

SECTION III
INITIAL CHECKS

3.1 INTRODUCTION

The following procedure is provided to facilitate initial performance checking of the Model 165 Gated Integrator. This procedure should be performed after inspecting the instrument for shipping damage (any damage noted to be reported to the carrier and to EG&G PARC), but before using it to make measurements. Should any difficulty be encountered in carrying out these checks, communicate with the factory or the authorized factory representative. It is not the purpose of these checks to demonstrate that the instrument meets its specifications, but rather to show that it has arrived in good working order. Each instrument receives a painstaking alignment and check-out before leaving the factory. Users can have a high degree of confidence that their Models 165 will meet or exceed all specifications if no shipping damage has occurred. The following checks will usually reveal any such damage.

Note that the check-out procedure calls for operating one Model 165 in conjunction with the Model 162. If the customer has two M165 modules, they should be checked out one at a time. Once each has been checked, dual-channel checks can be performed as indicated in Subsection 3.5.

3.2 EQUIPMENT NEEDED

(1) Square-wave source capable of furnishing 0-to-100 mV 1 kHz square waves, and 0-to-1 V 1 kHz square waves—the two to be synchronous. It should be possible to set the 100-mV level to within a few percent of the desired level. The 1 V level, however, is not critical as long as the amplitude is high enough to trigger the M162 (±0.5 V minimum). These requirements are easily met by using a 1 V source followed by a 10:1 attenuator, arranged so that the 1 V square wave can be applied to the Ext. Trigger input of the Model 162 and the 100 mV square wave can be applied to the Signal Input of the Model 165. The 100 mV source should be such that the amplitude will be 100 mV when loaded with 50 ohms. The 1 V source will be driving the 50 kΩ input impedance of the Trigger Input, so that loading considerations for the 1 V signal should not be critical.

The TEKTRONIX type 114 Pulse Generator is a suitable signal source.

NOTE 1: If the available generator does not produce a square wave that is unipolar with respect to ground, but rather one that goes plus and minus, the procedure will have to be adapted to the generator characteristics. With a unipolar generator, the sampled levels will be +100 mV and 0 V. In the case of a generator that swings plus and minus at the output, the sampled levels will be +50 mV and −50 mV, and the indicated M162 output levels will change accordingly.

NOTE 2: A basic assumption underlying this procedure is that the generator's trigger output and signal output are in phase. Some generators provide a trigger output that is 180° out of phase with the signal output. Where this is the case, be sure to select negative-slope triggering at the Model 162 mainframe, even though the instructions call for triggering on the positive slope.

(2) Oscilloscope suitable for monitoring 1 μs, 5 V pulses.

(3) Source of +5 V (TTL level).

(4) Watch with a second hand, or a stop watch.

(5) Coaxial cables having a characteristic impedance of 50 ohms and fitted with BNC connectors.

3.3 PRELIMINARY STEPS

(1) On the M162, check the position of the rear-panel Line-Voltage-Selector switch. For operation from a line voltage in the range of 210-250 V ac, "230" should show. Do NOT apply power.

(2) Plug the Processor Module into the "A" (left-hand) module receptacle and tighten the two thumbscrews. Now plug in the line cord and turn the Power switch on. Allow at least 15 minutes for the instrument to warm up before proceeding.

3.4 MODULE CHECKS

3.4A CHECKS IN THE EXTERNAL-TRIGGER MODE

(1) Set the controls as follows:

Mainframe

% Initial A: 10% (one revolution from fully counterclockwise position)
% Initial B: fully counterclockwise
Aperture-Delay Range: 1 ms (be sure inner knob is set to mSEC)
Aperture Duration: 5 μs (multiplier to CAL)
Scan Time: 10 s (multiplier to CAL)
Function: A (digital storage OFF)

Time Constant: 0.1 ms (multiplier to CAL)
Trigger-Mode pushbuttons: EXT depressed; all others released
Scan-Select pushbuttons: all released

Model 165
Time Constant: 1 μs
Sensitivity: ZERO CHECK
Pushbuttons: EXP/SUM, CAL, and DC/AC depressed; all others released

(2) Triggering

(a) Connect the 1 V, 1 kHz trigger signal to the Trigger INPUT connector (mainframe front panel).

(b) Adjust the mainframe TRIGGER LEVEL control to establish proper triggering—as indicated by a steady glow of the TRIGGERED lamp.

(3) Zero and Gain Calibration (Baseline Delay to be "off—fully counterclockwise)

(a) Adjust the Model 165 ZERO control for "0" panel-meter indication.

(b) Move the SENSITIVITY switch to the 5 V position. Then set the screwdriver adjustment associated with the CAL pushbutton for exactly full-scale panel-meter indication.

(c) Release the CAL pushbutton and set the SENSITIVITY switch to 100 mV.

(4) Signal Processing—Manual Delay

(a) Leaving the 1 V trigger connected, connect the 0-to-100 mV square wave to the M165 INPUT. **NOTE:** Be sure to take into account the loading effect of the 50 Ω input impedance; the signal should be 100 mV when loaded with 50 Ω.

(b) Note the panel-meter indication, which should be nominally full-scale to the right. The tolerance is simply that of the source's signal amplitude. Adjust the source amplitude as required to get exactly full-scale meter indication. (If the meter stays at "0", re-adjust the TRIGGER LEVEL control.)

(c) Begin rotating the % INITIAL A dial clockwise. At about the 50% point the meter indication will drop to "0", indicating that the lower level of the 0-to-100 mV square wave is being sampled. The actual point where the crossover from full scale to "0" occurs will vary according to the symmetry of the input square wave. From 50% to 100% delay (five revolutions to ten revolutions), the "0" indication will be maintained. If the period of the input signal is a bit short, towards 100% delay the meter indication might rise again to full scale, indicating that the upper level of the next cycle is being sampled. After verifying the indicated behavior, set the % INITIAL DELAY dial to 10%.

(5) Signal Processing—Scanned Operation

(a) Depress the SCAN SELECT "A" pushbutton.

(b) Hold the SCAN SELECT RESET pushbutton. While the button is held down, the panel meter will indicate nominally full scale. At some convenient time, release the RESET pushbutton. The panel meter will continue to indicate full scale for about four seconds, indicating that the upper level of the input square wave is being scanned. Then the panel meter indication will drop to "0", where it will remain for five seconds as the lower level of the square wave is scanned. These nine-second (nominal) cycles of four seconds of full-scale indication followed by five seconds of "0" indication will follow one another automatically.

(c) If desired, the above-mentioned operation may be monitored on the oscilloscope. Connect the Y-axis input of the scope to the mainframe f(t) output connector; scope triggering should be obtained from the signal generator.

(d) The oscilloscope is required for the next check. Set the main-frame SCAN TIME to 0.1 s, and the APERTURE DURATION to 50 μs. With scans proceeding as in the previous step, depress the 15 ns APERTURE pushbutton on the M165. The square wave should now be displayed with its corners rounded off on the top leading edge and on the bottom trailing edge, with "staircase" steps on the edges. Depress the 10 ns, 5 ns, and 2 ns pushbuttons in turn. Each pushbutton should produce progressively further rounding of the square wave.

Release all APERTURE pushbuttons on the M165 and return the M162 SCAN TIME to 10 s. Leave the APERTURE DURATION at 50 μs.

(6) Channel Sync

The test for proper operation of Channel Sync simply requires that the procedures in steps

5a and 5b be repeated while TTL-level voltages are applied to the CHAN SYNC BNC connector.

(a) Set the CHAN SYNC toggle switch to TTL-level "1".

(b) Using an external power supply, apply 5 V to the CHAN SYNC connector.

(c) Now repeat step 5b; operation should be exactly as noted for that step.

(d) Set the power supply to zero volts (i.e., low impedance to ground).

(e) Repeat step 5b; the meter may drift, but should give no indication that a scan is taking place.

(f) Change the CHAN SYNC toggle switch to TTL-level "0", and repeat step 5b. Now a zero-voltage "signal" (low impedance, or short-circuit to ground) should allow normal operation; a TTL-logic "1" signal should inhibit normal operation (although, again, the meter may drift).

(7) Baseline Sampling and Gate Out

(a) On the M162, the Aperture Duration should still be set at 50 μs (multiplier to CAL).

(b) Connect the oscilloscope signal input to the M165 GATE OUT connector. The scope should be triggered on the positive edge of the same signal as is being used to trigger the M162 (the negative edge if the trigger and signal are 180° out of phase). The sweep time should be 100 μs per cm.

(c) A 50 μs marker pulse should be visible on the scope. As the scope scans repeat, this marker pulse will be observed to "slide" across the screen, taking nominally nine seconds to complete each scan. At the end of each M162 scan, the pulse position will reset to the beginning of the scope trace and then start to "slide" across the screen again.

(d) Turn the BASELINE SAMPLE DELAY control (M165) clockwise. As soon as the control is rotated off the fully counterclockwise position, a second 50 μs pulse will be noted. This one will not scan. Its position is determined by the setting of the BASELINE SAMPLE DELAY control. With the control as far counterclockwise as it can be rotated without turning off the Baseline Sampling function, the second pulse will be positioned near the beginning of the scope trace. With the control fully clockwise, this pulse will be at the end of the trace.

(e) Note the panel-meter indication as a function of the position of the two marker pulses. When both pulses are on the same half of the input square wave (both on the left half of the scope trace or both on the right half), the panel meter will indicate "0". When both pulses are on opposite halves of the trace, the panel meter will indicate nominally full scale, either plus or minus. When the signal aperture marker is on the left half of the trace and the baseline aperture marker on the right, full-scale positive output is obtained. When their positions are reversed, full-scale negative output is obtained. If the oscilloscope has dual-sweep capabilities, it may prove instructive to monitor the input signal simultaneously, so that the position of the apertures relative to the input square wave can be more easily seen.

(8) Summation Averaging Checks

(a) On the M162, release the SCAN SELECT "A" pushbutton and set the APERTURE DELAY RANGE to 5 μs (check the inner knob!); set the APERTURE DURATION to 0.5 μs. On the M165, set the TIME CONSTANT to 1 ms.

(b) Depress the M165 CLEAR pushbutton (meter indication will go to zero), and while holding that pushbutton depressed, release the M165 EXP/SUM pushbutton.

(c) At any convenient time, release the CLEAR pushbutton. The meter indication will begin rising linearly from zero, and will reach full scale in about two seconds. It will not stop at full scale but will continue to rise to the limit of the pointer's travel. (**NOTE:** The exact timing is not critical for this check.)

(d) Depress the EXP/SUM pushbutton to restore exponential averaging.

3.4B INTERNAL-TRIGGER MODE CHECKS

(1) Triggering

(a) Release the EXT Trigger pushbutton. The TRIGGERED lamp should extinguish.

(b) Depress the INT Trigger pushbutton. The TRIGGERED lamp should glow steadily again. **NOTE:** Although unlikely, it is possible that internal triggering will not start. If such be the case, alternately release

and press in the INT pushbutton until internal triggering is established—as indicated by the TRIGGERED lamp.

(2) Signal Processing

(a) Set the APERTURE DELAY RANGE to 1 ms (check inner knob). APERTURE DURATION should already be set to 0.5 μs. On the M165, set the TIME CONSTANT to 10 ms.

(b) Set the M165 SENSITIVITY switch to Zero Check, and press the CLEAR pushbutton. The meter indication should be "0".

(c) Depress the CAL pushbutton and move the SENSITIVITY switch to 5 V (in that order). The meter indication will begin rising, approaching full scale asymptotically. The observed time constant will be nominally 20 seconds; that is, the meter will reach 63% of full scale in 20 s. After 40 s, the meter indication should be nominally 86%; after 60 s it should be 95%; after 80 s it should be 98%; and after 100 s it should be within 1% of full scale. (The actual time required may vary somewhat from these numbers. The important thing is that the indicated general behavior is observed.)

(d) Rotate the SENSITIVITY switch to Zero Check (leave CAL depressed). The meter indication will now decrease, asymptotically approaching zero.

(e) Momentarily depress the CLEAR pushbutton. The meter indication will quickly go to "0".

3.4C HOLD CHECKS

(1) Zero Hold

(a) Decrease the M165 TIME CONSTANT to 100 μSEC.

(b) Release the INT Trigger pushbutton. The TRIGGERED light will extinguish, showing that the unit is no longer triggering.

(c) Note the panel meter indication. For as long as the unit is not triggering, the meter-indication drift should be less than 1% of full scale per second.

(2) Full-Scale Hold

(a) Depress the EXT Trigger pushbutton to restore triggering. The meter indication will quickly go to "0" (if not already there).

(b) Rotate the SENSITIVITY switch to the 5 V position (CAL should still be depressed). The meter indication will go to full scale in less than one second.

(c) Release the EXT Trigger pushbutton. Note the panel-meter indication. For as long as the unit is not triggering, the meter indication drift should be less than 1% of full scale per second.

NOTE: This completes the Initial Checks for a system consisting of a Model 162 and a single Model 165. If there is a second Model 165 to be checked, plug it into module receptacle "B", and return to step 1 of Subsection 3.4A, the only differences being that the FUNCTION switch, instead of being set to "A", is set to "B", and that the settings of the % INITIAL A and % INITIAL B dials must be reversed. Once the second Processor Module is checked out, go to Subsection 3.5 to check dual-channel operation.

3.5 DUAL-CHANNEL OPERATION

These checks presuppose that the operator has two M165's, and that both have been checked out according to the previous procedures.

(1) Both modules should be plugged in, and the controls should be set as indicated in step 1 of Subsection 3.4A. The trigger input should be connected and the Trigger-Level control adjusted for proper triggering. However, there is no need to connect the 100 mV signal: the M165 Modules are checked by using their internal calibration levels.

(2) Rotate both SENSITIVITY switches to the 5 V positions. (The CAL pushbuttons should still be depressed.)

(3) With the mainframe FUNCTION switch set to "A", the panel meter should indicate full scale.

(4) Change the FUNCTION switch to "B". The panel meter should continue to indicate full scale.

(5) Change the FUNCTION switch to "A – B" (A minus B). The meter indication should go to "0", plus or minus a percent or two of full scale. (The exact reading will depend on how well the "zero" and the "calibrate" operations were performed when the modules were checked out individually.)

This completes the Initial Checks. If the indicated results were observed, one can reasonably conclude that the M165 is working properly. Note that no dual-channel checks were furnished for the case where dual-channel operation is attempted

with one M165 Processor Module and one M164 or M163 Processor Module. Operation with these combinations is perfectly feasible and there should be little difficulty in adapting the individual procedures to checking out dual-channel operation with one module of each type.

SECTION IV
OPERATING INSTRUCTIONS

4.1 CONTROLS, CONNECTORS, AND INDICATORS (Figure IV-1)

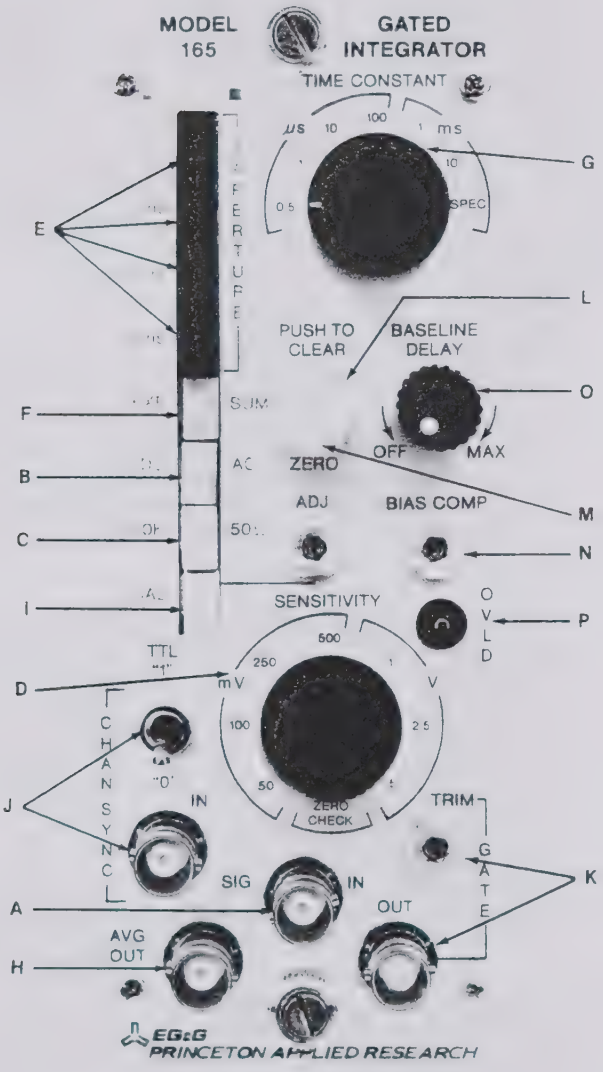


Figure IV-1. MODEL 165 GATED INTEGRATOR

A. SIG IN: Signals to be processed are applied to this connector. The coupling mode and input impedance are determined by buttons "B" and "C" respectively.

B. AC/DC Selector pushbutton: The IN position selects dc coupling. The OUT position selects ac coupling (series capacitance = 1 μF).

C. INPUT IMPEDANCE Selector: The IN position selects an input impedance of 10 kΩ. The OUT position selects an input impedance of 50 Ω.

D. SENSITIVITY switch: This switch allows full scale sensitivities from ±50 mV to ±5 V to be selected. In addition, there is a ZERO CHECK position, in which the internal circuitry is disconnected from the SIG IN connector (but the connector itself remains internally terminated in either 50 Ω or 10 kΩ as selected by the INPUT IMPEDANCE selector). This Zero-Check position allows the instrument to be zeroed using the outer knob ("L") of the dual-concentric ZERO/CLEAR control. (The unit must be triggered to respond to zero adjustments.)

E. APERTURE DURATION Selectors: This set of four pushbuttons is used to select aperture durations (AD) of 15, 10, 5, or 2 ns. These pushbuttons override the mainframe Aperture switch; as long as one of these pushbuttons is IN, the setting of the mainframe Aperture Duration switch has no effect on the M165. It will, however, still set the AD on a second module (M164 or M165) if its AD pushbuttons are OUT. Only one of these pushbuttons per module can be IN at any one time for proper operation.

F. EXP/SUM Selector: The IN position selects exponential averaging, in which the output asymptotically approaches the steady-state value. If broadband white noise is assumed, there will be a Signal-to-Noise Improvement (SNIR) = $(2N)^{1/2}$ (N = number of repetitions required to achieve 63% of steady-state output), providing at least 5N repetitions have occurred. In the OUT position, linear (or "summation") averaging is selected, in which the output does not approach a steady-state value, but rather rises in direct proportion to the number of repetitions. In this mode SNIR = $(R)^{1/2}$, where R is the number of repetitions that occur.

G. TIME CONSTANT: This switch directly sets the averaging time constant—and hence the attainable improvement in signal-to-noise ratio during exponential averaging. In summation averaging, the time constant affects the ΔE_{out} per repetition.

H. AVG. OUT Connector: The averaged output of the module—before mainframe processing—is provided at this connector (impedance 50 Ω). Full-scale output is ∓10 V, inverted at all times with respect to the input. During baseline-sampled operation, the averaged output is the difference between the signal-sample and the baseline-sample levels.

I. CAL pushbutton: When IN, this pushbutton applies an internally derived (1% accurate) +5 V dc level to the input (but isolated from the SIG IN connector), allowing the gain to be calibrated when the SENSITIVITY switch is in the 5 V position. The associated front-panel SENSITIVITY screwdriver adjustment is then set for full-scale output (unit must be triggering and ZERO must have first been properly adjusted). If 50 Ω input impedance is selected, CAL function open-circuits the SIG IN connector. If the 10 kΩ input impedance is selected, the SIG IN connector is internally terminated in 10 kΩ.

J. CHANNEL SYNC Input and TTL "1", "0" Logic switch: In systems equipped with two M165 modules, it is possible to have each module sample on *alternate* mainframe triggers. (Such procedure is useful for examining two signals alternately applied to the input.) This demultiplexing is accomplished by applying a TTL square wave to the CHANNEL SYNC input of both units. The Logic switches determine which unit is active on logic "1" and which on logic "0".

K. GATE OUT: A positive-going pulse is provided for each gate opening. These pulses have an amplitude of nominally 150 mV (terminated in 50 Ω) and rest on a baseline of +250 mV. The baseline-sampling gate pulses are identifiable by a positive "spike" of about 75 mV on their leading edges. The pulse width depends on the selected Aperture Duration (pulses equal Aperture Duration down to about 50 ns). For Aperture Durations selected with M165 pushbuttons, a 100 ns marker pulse is provided for the Signal Channel and a 200 ns marker for the Baseline Channel. The leading edge of the marker pulse is coincident with the gate opening. Use of the Gate-Out pulse for positioning the baseline sample is described in Subsection 4.2K.

Associated with the GATE OUTPUT is a TRIM adjustment, which allows fine tuning of the mainframe's Aperture-Duration settings. When the TRIM is in the center of its adjustment range, the mainframe's AD's will be as indicated by the markings at its AD selector switch. Moving the TRIM "off center" allows a ±10% variation from that indicated setting—allowing the user to match the AD characteristics of two M165 modules.

Note that the *M165's* AD settings (2, 5, 10 or 15 ns) are *not* affected by the TRIM adjustment.

L. ZERO ADJ Control (outer knob of dual-concentric control): Allows the user to adjust the zero level. The unit must be triggering, and time constant considerations apply. The range is nominally ±45% of full scale but appreciable non-symmetry with respect to "0" may occur. The unit can be isolated from the applied signal by setting the SENSITIVITY switch to the ZERO CHECK position while making the zero adjustment.

M. PUSH TO CLEAR: When pressed, this pushbutton (center of dual-concentric control) shorts out the integrator, allowing it to be instantly cleared. It is useful for establishing zero output, independent of the triggering requirement mentioned in regard to the ZERO control. This is a *system* clear; if there are two modules, pressing CLEAR on either one will reset both.

N. BIAS COMPENSATION (screwdriver adjustment): Allows offset current to the Signal Channel Integrator to be compensated, thereby achieving minimum drift. BIAS COMP is adjusted with the time constant set to minimum and with the unit not being triggered. Note that BIAS COMP has no effect on the Baseline Channel Integrator.

O. BASELINE DELAY: This control activates the baseline sampling function and sets the delay of the baseline sample. In the fully counterclockwise position (OFF), the function is disabled and no baseline sampling occurs. As the control is rotated clockwise, baseline sampling is activated; the delay of the baseline sample with respect to the trigger varies linearly with the control rotation from a few percent to one hundred percent of the Aperture Delay Range.

P. OVLD LIGHT: When voltage excursions at the input exceed plus-or-minus five times the setting of the SENSITIVITY switch, this lamp will light. This indication applies primarily to an overload due to noise, because a *coherent* input signal will cause an overload whenever it exceeds the full-scale setting. Overload due to a coherent signal will first be indicated by "pegging" of the panel meter, rather than by illumination of the overload lamp.

Regardless of the overload indication, note that the maximum allowable input is ±5 V rms for a continuous signal.

4.2 INPUT SIGNAL PROCESSING

4.2A INPUT IMPEDANCE SELECTION

The M165's input impedance is either 50 Ω (pushbutton OUT), or 10 kΩ (pushbutton IN). In those applications calling for the highest possible resolution, and where the source impedance is 50 Ω, the 50 Ω input should be used. Also, to be assured of the best performance, cables having a characteristic impedance of 50 Ω should be used to interconnect the signal source and the M165 SIGNAL INPUT connector. (Suitable cable types include RG58C/U and RG188A/U.) It is possible, however, to use cables having a characteristic impedance higher than 50 Ω. In such cases, the cable's characteristic impedance should be chosen to match the source impedance. At the input to the M165, a resistor should be placed in series with the cable to make up the correct load impedance for the source. The value of the series resistor is given by the formula $R_{SERIES} = Z_{SOURCE} - 50\ \Omega$. Note, though, that the use of a series resistor will result in an attenuation of the signal being delivered to the M165.

For operation from source impedances so high that the 50 Ω input of the M165 would constitute a significant load, one should choose the M165's 10 kΩ input. When this impedance is selected, an additional buffer amplifier is inserted in the signal channel. This amplifier reduces the signal-channel bandwidth, causing some reduction in high-frequency response compared to that available with the 50 Ω input impedance. Additionally, any high-frequency attenuation caused by the input-shunt capacitance of the M165 will increase as the source impedance becomes higher. This input-shunt capacitance is typically 25 pF.

Sometimes, such as when one is using certain external attenuator probes (e.g., EG&G PARC #1150-2400-08S), a shunt capacitance *higher* than 25 pF will be required so that the attenuator's response can be properly trimmed by means of its compensation adjustment. (The probe's response is affected by its resistance, shunted by its compensator, in series with the M165 input resistance, shunted by the above-mentioned input-shunt capacitance.) Any required additional capacitor can be installed behind the back panel of the M165, on its SIGNAL INPUT connector.

4.2B INPUT COUPLING

The pushbutton labeled DC/AC allows the choice of either dc coupling (pushbutton IN), or ac coupling (pushbutton OUT). DC coupling is preferred when measuring low-frequency phenomena. But where dc drift at the signal source is a consideration (especially over long intervals of analysis), ac coupling may be preferred. In the latter case, one may be faced with the dilemma of choosing ac coupling to avoid the effects of dc drift by the source, but by so doing, attenuating important low-frequency components in the input signal. To compute the effects of ac coupling on the low-frequency response of the M165, use the following data:

(1) Frequency at which response is down 3 dB

  (a) 50 Ω input: 3200 Hz

  (b) 10 kΩ input: 16 Hz

(2) Below these frequencies the response goes down at the rate of 6 dB/octave (20 dB/decade).

(See Subsection 4.2K, Baseline Sampling, for an alternative solution to dc-drift problems.)

Figure IV-2 is a simplified diagram of the input circuits, showing the input configuration as a function of the chosen input impedance and coupling method.

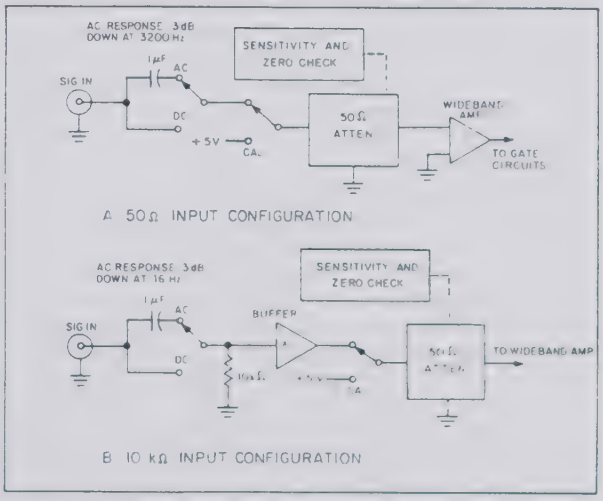


Figure IV-2. MODEL 165 INPUT CIRCUITS

4.2C INPUT VOLTAGE LIMITS

The maximum continuous-signal input (i.e., as opposed to noise input) that can be applied when operating dc-coupled is ±5 V rms. Higher voltages could cause damage to the input attenuator. When operating in the ac-coupled mode, the coupling capacitor protects the attenuator—allowing dc voltages as high as 50 V to be applied. Still, those continuous-frequency components which will be coupled through the capacitor should be limited to ±5 V rms. Duty-factor can be taken into account, however: levels higher than ±5 V may be applied momentarily.

Noise and nonsynchronous interference as large as five times the full-scale sensitivity setting (up to the 5 V input limit) may be applied without causing overload. An overload detector continuously monitors the circuit for input excursions in excess of the $\pm 5 \times$ FS limit; if the limit is exceeded, the front-panel OVERLOAD light will come "on". Occasional flickering of this indicator is generally not a cause for concern. But if the light is "on" most of the time, it is probable that appreciable distortion is being introduced. A lower input-sensitivity setting should then be chosen, to assure valid measurement results.

A *coherent* input signal cannot exceed $\pm$FS without causing input overload—as indicated by "pegging" of the panel meter. (Should the OVERLOAD light glow due to coherent-signal input, it would mean that a stupendous overload of $\pm 5 \times$ FS had been attained.)

4.2D ZEROING AND CALIBRATION

Prior to using the M165 for a signal-recovery measurement, it is a good idea to adjust the "zero" and the gain calibration. The M165 has been designed to make these operations quite simple.

(1) Before turning on the mainframe power, ascertain that the meter pointer is at zero. If it is not, carefully set it to zero by means of the meter's screwdriver adjustment.

(2) Turn on the power and allow the instrument to warm up for half an hour.

(3) With the M162 NOT triggered, set the M165's Time-Constant switch to 0.5 μs, and press the PUSH TO CLEAR button. The panel-meter indication should immediately go to zero. (Be sure the channel-bin occupied by the M165 is the one selected for panel-meter display.) The meter's pointer will then slowly drift away from zero. Before it reaches the limit (in whichever direction it is moving), adjust the BIAS COMP as required to stop its drift. Then press PUSH TO CLEAR again, to restore the zero indication. Some small additional fine tuning of the BIAS COMP adjustment may be required to stabilize the meter indication.

    If there are two M165's in the mainframe, repeat the above procedure for the second one.

(4) Trigger the M162 from an external source. If one is preparing to examine a signal, the Aperture Delay Range and Aperture Duration should be set to the intended signal-recovery value (see Subsection 4.2J). In the interest of rapid response, the ADR should be slightly longer than one-half the trigger period.

(5) Set the BASELINE DELAY control to the fully counterclockwise position (off).

(6) Set the SENSITIVITY switch to the ZERO CHECK position. Then set the ZERO adjustment for "0" panel-meter indication. Be sure to allow time for the instrument to respond fully to each change in the control setting. The response time will depend on the trigger rate, time constant, and aperture duration; thus it can vary over a wide range.

(7) When you are satisfied that no further improvement can be made in the zero adjustment, set the SENSITIVITY switch to 5 V, and press the CAL pushbutton. Now carefully set the screwdriver adjustment related to the CAL pushbutton for exactly full-scale meter indication. As before, allow sufficient time for the instrument to respond fully each time the setting is changed.

(8) When no further improvement seems possible, release the CAL pushbutton. The zero and gain calibrations are complete.

A valuable feature of the M165 is that the previous settings may be checked and adjusted without having to disconnect the signal from the SIGNAL INPUT connector. When the SENSITIVITY switch is set to ZERO CHECK, the applied signal will "see" the same *input* circuit but it will not be applied to the signal-processing circuits. When CAL is depressed, the internally derived +5 V calibration voltage does not appear at the SIG IN connector.

Note that the ZERO CHECK overrides CAL; if CAL is depressed at the same time that the SENSITIVITY switch is set to ZERO CHECK, zero level is applied to the signal-processing circuits. To get full-scale deflection with the CAL pushbutton depressed, the SENSITIVITY switch must be set to "5 V".

There may be instances when one wishes deliberately to introduce an offset by means of the ZERO control (e.g., when a non-zero baseline would give a more convenient display). Conversely, when the unit is operating in the dc-coupled mode, the ZERO control can be used to null out any dc offset accompanying the input signal (within the nominally $\pm 45\%$ of full-scale range of the ZERO control). This technique must be used with caution in baseline-sampled operation, however, since it reduces the available dynamic reserve.

4.2E SYNCHRONIZATION

Synchronization is a critical factor for any boxcar integrator. The gate must open at a controlled time (relative to the signal being processed), in order for the unit to recover useful information. In the case of the M165, the availability of baseline sampling and Alternate Channel Triggering (ACT) make the matter of synchronization somewhat more complex than for ordinary boxcars.

First, let us examine briefly the simplest case—where there is neither baseline sampling nor ACT. In most instances, the unit will be operated in the EXTERNAL Trigger mode, as selected by a mainframe pushbutton. With each repetition of the signal, a trigger having a fixed time relationship to the signal of interest is applied to the mainframe TRIGGER INPUT connector. Each trigger initiates an Aperture Delay Range (ADR), as set by the mainframe APERTURE DELAY RANGE controls. Somewhere during the interval defined by the ADR, the signal is sampled.

These samplings can be made to occur at the same time-interval after each trigger, in which case the procedure is called "fixed-point operation". (This needs elaboration: every sample is taken at a fixed time-interval following each trigger. However, this means that the time-interval is "fixed" only until the user changes it. The INITIAL DELAY control permits the operator manually to lengthen or shorten the time-interval at will—essentially throughout the extent of the ADR.) Or, the samples can be made to "scan" across the Aperture Delay Range, so that each sample is taken at a later time, with respect to the trigger, than was the previous sample. Thus the ADR (which is initiated by trigger signals) determines the range throughout which a sample interval can be placed manually (fixed-point operation), or the range across which a sample interval can be swept automatically (scanned operation).

(Note that the above discussion has said nothing about the *duration* of each sample; only the *positioning* of the sample was described. The duration of the sample, called Aperture Duration (AD), can be set both by the mainframe controls and—for the four shortest AD's—by pushbuttons on the M165.)

This brief discussion of simplest-case synchronization is, of course, not intended as a treatise on boxcar operation. It is essential that the user fully understand operation of the Model 162 mainframe, as discussed in the M162 manual, before he can be reasonably certain that the aperture timing in the M165 will be as intended.

To return to Synchronization: in baseline-sampling operation, the trigger is utilized for two different functions. The first trigger signal is used in a signal-sampling cycle as described above for either fixed-point or scanned operation. The next trigger, however, would be fed to a baseline-sampling circuit. The following trigger again would be fed to the signal-sampling circuit, and so on. More details on baseline sampling are given in Subsection 4.2K.

In alternate-channel triggering, the trigger is directed alternately to one of a pair of M165's in the same mainframe. And, of course, either or both of the M165's additionally may be utilizing baseline sampling. (ACT is described in detail in Subsection 4.2L.)

In summary, for any meaningful application of the M165/M162, the relationship of the trigger to the signal (or signals) of interest must be completely reliable.

4.2F EXPONENTIAL vs SUMMATION AVERAGING

The M165 gives the user the option of exponential (weighted) averaging, or true (linear, or summation) averaging. When operated in the EXP averaging mode (pushbutton IN), the output level asymptotically approaches a steady-state value of G × Input Level, where G is the instrument gain. The time required for the output to reach its final level is five "observed time constants" (OTC), where one OTC is the time required for the signal to reach 63% of steady state.

(Recall that the output of an integrator will attain a level equal to 63% of the input voltage after a time interval equal to one "time constant", or TC. However, in boxcar operation, the sampling interval—or Aperture Duration—is normally set much shorter than the time constant being used. Consequently, many samples must be taken before the total *analysis time* equals one TC. The shorter the Aperture Duration, and the longer the period between samples, the longer it will take to accumulate analysis time equal to one TC. The total elapsed time needed to accumulate one TC is called the "observed time constant", or OTC.)

Once the output reaches steady state, there is no further change in the output level—regardless of how many additional repetitions of the input signal there may be. Thus, if "N" is the number of repetitions required to reach 63% of full scale, then 5N is the number of repetitions required to reach (practically) steady state. Assuming a white-noise background, the signal-to-noise improvement ratio (SNIR) will be $(2N)^{1/2}$ after 5N repetitions have occurred. No further improvement in SNIR occurs as the number of repetitions is increased beyond 5N. Note, too, that this is a weighted average: the most recent repetition has more influence on the output level than the one preceding—which had more influence than the one preceding it—and so forth on back to the early repetitions, which have negligibly small influence. Figure IV-3 illustrates this weighting function.

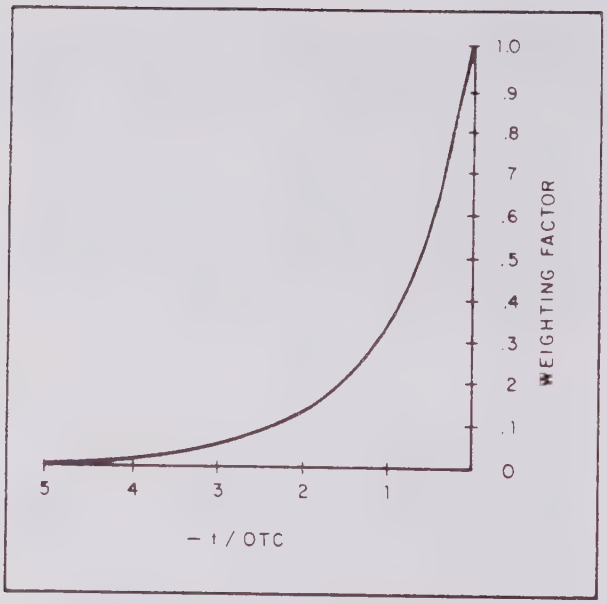


Figure IV-3. EXPONENTIAL AVERAGING WEIGHTING FACTOR AS A FUNCTION OF –t/OTC

As an example of weighting, assume a measurement in which the OTC is four seconds, and determine from Figure IV-3 the weighting of samples taken one second ago, two seconds ago, and four seconds ago. First, determine the value of –t/OTC for each case. With an OTC of four, and "t" values of –1, –2, and –4, –t/OTC will be +1/4, +1/2, and +1, respectively. The graph shows that the corresponding weighting factors will be 0.78, 0.61, and 0.37, respectively. The most recent sample will be more than twice as important in determining the final value as will be the sample taken four seconds ago.

When operated in the SUM averaging mode (pushbutton OUT), the instrument becomes a linear averager—one in which all repetitions of the signal contribute equal volt-second increments to the output level. The output does NOT asymptotically approach G × Input Level; instead, it increases by the *same* amount with each repetition of the input signal and is already at "G × Input Level" at the end of *one* TC, and will keep going up. (Obviously, after not too many repetitions, the output will build up to a point at which it can increase no further because it has reached the overload level.) In other words, in linear averaging, the output is simply the sum of the samples taken. In this mode of operation, the SNIR is $R^{1/2}$, where R is the number of times in the analysis that the unit was triggered. Thus, in summation averaging, the SNIR is *independent* of both the time constant and the aperture duration. Both of these parameters do, however, affect the size of the volt-second increments to the output that occur with each repetition. That is, they determine the rate of growth of the output level.

Figure IV-4 shows the M165 output response as a function of time for the two averaging modes. With exponential averaging, the output is within 0.7% of steady state after 5 × OTC. If the same signal were processed with summation averaging, the output would reach the same level after *one* OTC. If the measurement were to be continued, the output would continue to rise until output overload occurred.

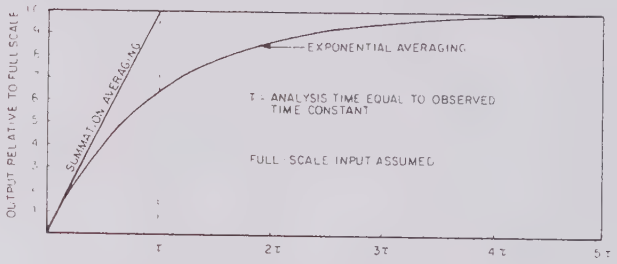


Figure IV-4. OUTPUT RESPONSE AS A FUNCTION OF ANALYSIS TIME FOR BOTH EXPONENTIAL AND SUMMATION AVERAGING

Practically speaking, the principal difference between linear and exponential averaging is that, for a *given number* of repetitions of the event under study, linear averaging will give a better SNIR. This is seldom a significant advantage, however; usually there is no difficulty in using exponential averaging and simply allowing a larger number of repetitions to occur. By so doing, one may obtain an equivalent—or even superior—SNIR, together with an output level more easily related to the input level. Moreover, there is no possibility of using summation averaging when scanning across a signal in order to recover the entire waveform. Consequently, exponential averaging is used in most applications.

Still, situations may arise where the number of allowable repetitions is limited. Summation averaging might well be the better technique in such a case. Consider the following example.

Suppose that the effect under study deteriorates with repeated stimulation, so that the maximum number of useful repetitions is limited to 500. Further suppose that the resolution requirement is 1 μs, and that an aperture duration of 1 μs is being used. We want to utilize exponential averaging, so we should be at the steady-state value after 500 repetitions. As mentioned earlier in describing exponential averaging, this means that 5N = 500; therefore, N = 100. In words, the latter equation means that after 100 repetitions, we should have accumulated *one* TC. With an AD of 1 μs, and 100 repetitions, we therefore need a TC setting of 100 μs. With these parameters, the output will reach 63% of steady state after 100 repetitions, and 99.3% of steady state after 500 repetitions. The SNIR, on reaching steady state, will be 14.1, because $SNIR = (2N)^{1/2} = (2 \times 100)^{1/2} = 14.1$.

Now consider the same experiment, but this time utilizing linear averaging. Again, we assume that the required resolution dictates an AD of 1 μs. For the moment, however, we may ignore the TC setting; it will not influence the SNIR in linear averaging. We simply take our 500 samples, and arrive at a SNIR of 22.4, because now SNIR = $R^{1/2} = 500^{1/2}$ = 22.4. Under the given conditions, we have done better with linear than with exponential averaging.

We ignored the TC in the preceding paragraph because it did not affect the final SNIR; but the TC does affect the rate of increase of the output signal. Ideally, the TC selected should give as much output as possible without causing overload. Since linear averaging yields full-scale output after just one TC, we would arrange in this experiment to arrive at one TC at the conclusion of our 500 samples. So, with each sample having a duration of 1 μs, and there being 500 samples, we would wish a TC of 500 μs. If we choose a TC much shorter than 500 μs, we will attain our one-TC level earlier in the run, and succeeding samples will cause an overload. If we choose a TC much longer than 500 μs, we will have finished our run long before the output level attains full scale. The final level might even be so low as to make the drift and noise of the mainframe output amplifiers significant by comparison.

Since the M165 does not have a TC setting of 500 μs, we must choose between a setting slightly too short and a setting slightly too long. Even a slightly short setting would cause overload; a slightly long setting only means that the output level at the end of the run will not quite have attained full scale. We choose a TC of 1 ms—the next TC larger than the ideal (but unavailable) 500 μs.

At the risk of being repetitious, it must be pointed out again that this comparison of linear vs exponential averaging is with reference to single-point analysis. If the input signal is to be scanned, the only possible choice is exponential averaging. Also note that one must use exponential averaging during the previously mentioned zeroing and gain-calibration operations. As a final note in this comparison of averaging methods, we have purposely chosen an experiment in which the aperture duration was 1 μs. With AD's shorter than 1 μs, the double-gate operation of the M165 comes into play—reducing the number of repetitions required to attain a given output level. The double-gate feature of the M165 is explained in detail in Subsection 4.2G, which follows.

4.2G TIME CONSTANT AND APERTURE DURATION

Time Constant and Aperture Duration are important parameters in the operation of any boxcar averager; they directly affect both the rapidity of a measurement and the attainable improvement in signal-to-noise ratio. Because of the sophisticated design of the M165, both TC and AD must be examined in some detail.

Wherever TC is mentioned in this manual it refers to the actual setting of the TIME CONSTANT switch on the M165 front panel. As was mentioned earlier, however, in normal boxcar operation the aperture duration (i.e., the time-duration of each sample) is much shorter than the TC. So, most often, it will be convenient to think in terms of the *observed* time constant—as was done in the preceding section. Again, OTC takes into account not only the TC setting but the duty factor and duration of the aperture. (The duty factor equals the AD divided by the aperture period—or, what is the same thing, the AD divided by the trigger period.) The OTC, then, equals the selected time constant (TC) divided by the duty factor. For example, with a TC of 1 ms and a duty factor of 10^{-3}, the OTC would be one second. Since the output reaches 63% of steady state in one OTC, in five seconds the output would be within 0.7% of steady state. (Exponential averaging is assumed throughout this discussion unless otherwise stated.)

But the M165 is equipped with *two* gates, which operate in series. At AD's of 1 μs or longer, both gates open and close in unison, and the M165 functions as an ordinary gated integrator. At selected AD's shorter than 1 μs, the first gate, which is very fast, opens for the *selected Aperture Duration* to charge a capacitor through a fixed resistor with a resulting RC = 20 ns. The second gate, characterized by very low leakage, *opens for 1 μs* to sample the level of the capacitor charged by the first gate's opening.

This second gate then supplies current to the summing junction of the main integrator, with the result that the integrator output continues to move towards steady state for a full microsecond—even though the signal sample taken by the first gate may be as short as 2 ns. The net effect of this arrangement is to provide narrow, fast gating, with low leakage, accompanied by a shortening of the time constant to some value smaller than that selected with the TC switch.

From the foregoing, it should be apparent that OTC calculations derived from the TC setting are valid with the M165 only for AD's of 1 μs or longer. For AD's shorter than 1 μs, a new term is necessary for the M165: Apparent Time Constant (ATC). ATC is a more comprehensive parameter than TC; it is interchangeable with TC for AD's of 1 μs or longer, but it is the only correct parameter when it is desired to compute OTC with AD's shorter than 1 μs.

The speed-up due to the double-gate operation of the M165 cannot be characterized by a simple formula. However, it has been empirically measured

as indicated in Figure IV-5, which gives the number of repetitions required to reach 63% of steady state as a function of the selected time constant and aperture duration. As shown in the Figure, when the AD is less than 1 μs, the number of triggers (N) required for the output to reach 63% of steady state is smaller than would be indicated by projecting the upper section of each curve into the region where the AD is less than 1 μs.

Figure IV-5 can be used to determine ATC and OTC for all values of AD. ATC is calculated by simply multiplying N × AD. OTC is obtained by dividing ATC by the duty factor, where duty factor is AD/P or AD × Trr (P and Trr are the trigger period and the trigger repetition rate, respectively). In other words, the only change in the basic relationships is that ATC must be substituted for TC with AD's shorter than 1 μs.

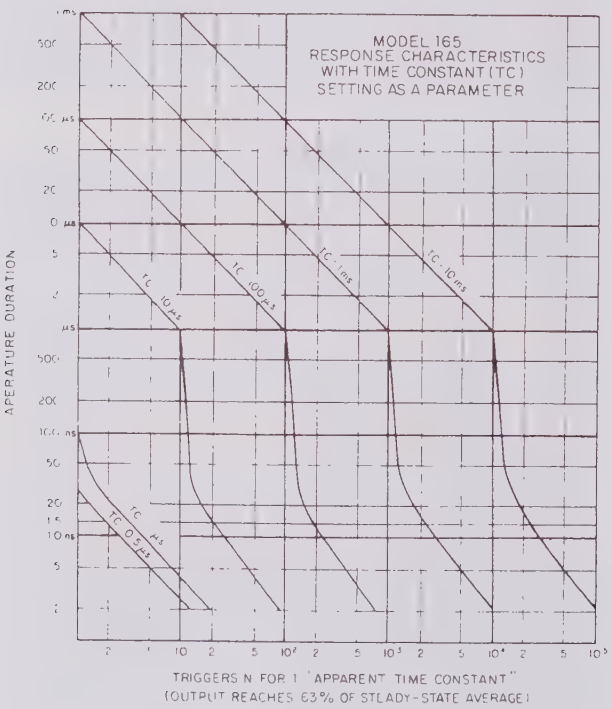


Figure IV-5. MODEL 165: N AS A FUNCTION OF APERTURE DURATION AND SET TIME CONSTANT

We are now in a position to discuss the signal-to-noise improvement ratio (SNIR) more thoroughly than was done in the preceding section. (Again, the assumptions are that we are using exponential averaging, and that the signal is accompanied by broad-band white noise.)

Four convenient ways of expressing SNIR are:

(1) $SNIR = (2N)^{1/2}$

(2) $SNIR = (2 \times OTC/P)^{1/2}$

(3) $SNIR = (2 \times TC/AD)^{1/2}$

(4) $SNIR = (2 \times ATC/AD)^{1/2}$

Where: TC is the setting of the TIME CONSTANT switch in seconds; AD is the selected Aperture Duration in seconds; ATC is the "speeded-up" time constant in seconds; OTC is the Observed Time Constant (real time for the output to reach 63% of steady state); P is the trigger period in seconds; and N is the number of triggers required for the output to reach 63% of steady state.

Now let us examine the applicability of each formula.

Formula (1) may always be used; an example of its use was given in the preceding section.

Formula (2) is applicable at all times, also—if one bears in mind that for AD's shorter than 1 μs, OTC will be calculated from ATC instead of TC.

Formula (3) may be used only when the AD is 1 μs or longer.

Formula (4) may be used at any time, but when AD's of 1 μs or longer are being used, its results will be the same as those from Formula (3).

The *mechanics* of selecting the Aperture Duration, and the logic underlying the selection of the Time Constant, will now be given some attention.

When a Model 165 is in use there are *two* sets of Aperture-Duration controls: one set is on the mainframe; the other set comprises the four AD pushbuttons on the M165. These pushbuttons offer the choice of 2 ns, 5 ns, 10 ns, and 15 ns aperture durations. The controls of the M165 override those on the mainframe. Any time one of the four Aperture Duration pushbuttons is depressed, the AD will be the one corresponding to the latched pushbutton—independent of the setting of the mainframe AD controls. (As might be expected, no more than one AD pushbutton on the M165 should be depressed at any given time.)

If there are two modules in use, the mainframe controls *will* set the AD for the second module if it is a Model 164, or if it is a Model 165 with all its AD pushbuttons released.

When all pushbuttons are "out", the mainframe Aperture-Duration controls are activated, allowing aperture durations over a wide range to be selected. In addition, space is provided on the M165 circuit board for the installation by the user of a "special" capacitor. (The space provided, and the location of connecting pins, allow for different lengths of capacitors.) If this special capacitor is installed, when the mainframe Aperture-Duration control is set to the SPEC position, aperture dura-

tions longer than those already provided by the mainframe control may be obtained. The formula relating the magnitude of this capacitor and the aperture duration is $C = AD/250$, where C is the capacitance in farads, and AD is the desired aperture duration in seconds.

Note that the fastest mainframe setting is 5 ns. This is valid to the extent that the vernier permits adjustment on this range to a maximum of 10×5 ns (vernier fully clockwise). However, it must be pointed out that, as the vernier is rotated counterclockwise, the fastest aperture actually obtainable with these mainframe controls is nominally 15 ns. Therefore, users are advised to use the M165 pushbuttons to achieve AD's of 15 ns or shorter. Note that the mainframe's indicated aperture durations will be accurate only when the M165's GATE TRIM adjustment is set to the center of its range, since this adjustment can vary the selected AD by $\pm 10\%$. (However, the Gate Trim adjustment does *not* affect aperture durations set by the M165's pushbuttons.)

The Time Constant is set by a switch on the front panel of the M165; it offers a range of 0.5 μs to 10 ms. In addition there is a SPEC position, in which the TC is determined by a user-installed capacitor. (Refer to entry for Time Constant, in Specifications section.)

In exponential averaging, the TC determines the degree of signal-to-noise improvement (improvement varies as the square root of the TC), as well as the time required to make a measurement (time varies directly as the TC). Clearly, for time efficiency, the TC should be no longer than that required to reduce the noise to an acceptable level.

With linear averaging, the TC does not affect the signal-to-noise improvement ratio ($SNIR = R^{1/2}$, where R is the number of repetitions in the run), but it does affect the size of the volt-second increments to the output.

To minimize the effects of drift and noise that may arise in the instrument, it is desirable that the output level at the end of the measurement be as near full scale as possible. Thus, in linear averaging, the TC should be that which allows the output to reach near full scale upon completion of the repetitions that are to be averaged. For example, if it is decided that the SNIR should be 100, then 10,000 repetitions will have to be averaged. The optimum TC will be the one which yields near-full-scale output after 10,000 repetitions. That particular TC may be determined with the help of Figure IV-5. (Recall that—assuming full-scale input—the number of repetitions required for the output to reach full scale, with linear averaging, is the same as the number required to reach 63% of full scale with exponential averaging.) For example, suppose the AD is 1 μs, and the number of repetitions to be averaged is 10,000. From the figure, the appropriate TC setting is shown to be 10 ms. This value would yield an output near—but less than—full scale after 10,000 repetitions.

It is important to understand that all of these SNIR calculations apply only when the noise to be reduced is "white", that is, noise having equal energy per unit bandwidth. Because actually encountered noise can have altogether different characteristics, the actual SNIR obtained may be better or worse than that given by the formula

4.2H RESOLUTION, MEASUREMENT TIME, AND SNIR AS A FUNCTION OF APERTURE DURATION

(1) RESOLUTION: The aperture duration (i.e., the time-duration of each sample) obviously will determine the ability of the instrument to resolve closely spaced changes in the input signal. As a matter of fact, in single-point analysis, the aperture duration is synonymous with the resolution: an AD of 5 μs will yield an analysis that has a resolution of 5 μs. In scanned operation, the AD does not give the resolution directly, but rather sets the maximum resolution that can be achieved. Whether this resolution is achieved depends upon the choice of the Scan Time. The minimum AD (hence, the maximum resolution) is limited by the length of time it will take to complete the analysis—as described below. The upper limit on AD is determined by the point at which two successive signals begin to merge into one another. If two signals separated in time by Δt seconds are recovered by scanning across them with an aperture of Δt seconds, the two will be blurred, but still distinguishable at the output. AD's longer than Δt will begin to merge the two signals together.

(2) MEASUREMENT TIME: In single-point analysis (using exponential averaging), an analysis time of $5 \times$ OTC is required for the output to reach steady state. Because OTC varies inversely with AD, the use of AD's shorter than absolutely necessary unduly prolongs the time required to recover the signal.

In scanned operation, the AD is even more critical because the scan time required to obtain a resolution equal to the AD varies as the inverse *square* of the AD. Thus it is even more important, in scanned operation, to appraise realistically the necessary resolution. The scan time may be made as *long* as one wishes; for proper signal analysis, however, there is a *minimum* scan time determined by the following formula:

$$MST = 5[(SPTC)^2 + (OTC)^2]^{1/2} \times ADR/AD$$

Where: MST is the minimum scan time in seconds; SPTC is the mainframe smoothing-time-constant; OTC is the observed time constant of the M165 (and, with AD's shorter than 1 μs, OTC is determined by ATC instead of by TC); ADR is the Aperture Delay Range in seconds; and AD is the Aperture Duration in seconds.

(Note that if one of the two time constants, SPTC or OTC, is a factor of three or more larger than the other, the effect of the smaller decreases to where it can generally be neglected in the MST computation.)

(3) SNIR: As pointed out in the earlier discussion of time constant, both AD and TC determine the SNIR when using exponential averaging. The narrower the aperture, the higher the SNIR. The trade-off one makes is in extended operating time. In scanned operation, particularly, resolution should be the dominant factor in selecting the AD. Once it has been determined according to realistically appraised resolution requirements, the TC's (M165 and mainframe smoothing) may be set as required to obtain the necessary SNIR.

In linear averaging, the SNIR varies as the square root of the number of actual repetitions, and is independent of TC and AD—although these parameters do affect the magnitude of the volt-second increments that occur at the output with each repetition. For best results, the aperture duration again should be set according to the resolution requirements, and the TC then adjusted to that value which will give near (but less than) full-scale output at the end of the measurement.

4.2I DROOP

With each repetition of the input signal, the M165 averages the signal only while the aperture gate completes the circuit (i.e., only for the aperture duration). *Between* apertures, the output level of the M165 is supposed to hold at the value averaged over the preceding aperture. The factors that determine the ability of the M165 to "hold" are the leakage current of the integrator, the ratio of the aperture duration to the aperture period (the duty factor), and the capacitance of the capacitor in the integrator circuit.

Correction of this drift occurs each time the aperture gate completes the circuit, and the degree of correction varies with the aperture duration and the time constant. However, correction is never total and there is always some net error, commonly referred to as "droop". If the maximum acceptable average error due to droop is arbitrarily set at 1% of the full-scale meter reading, then the maximum allowable trigger period—in terms of aperture duration and time constant—may be calculated as follows:

$$P_{MAX} = 5 \times 10^{10} C \times (1 - e^{-AD/\tau})$$

Where: P_{MAX} is the maximum trigger period in seconds; C is the value, in farads, of the integrating capacitor in the M165; AD is the Aperture Duration in seconds; and τ is the M165-set time constant, in seconds, or the ATC, in seconds. (Recall that ATC, computed from Figure IV-5, must be used when the AD is less than 1 μs.) The value of C varies according to the setting of the *M165 Time Constant switch*, as shown in Table IV-1.

M165-Selected Time Constant	C in Farads
0.5 μs	70×10^{-12}
1 μs	140×10^{-12}
10 μs	1×10^{-9}
100 μs	1×10^{-8}
1 ms	1×10^{-7}
10 ms	1×10^{-6}
SPEC	User Determined

Table IV-1. INTEGRATOR CAPACITOR vs TIME CONSTANT

The derivation of the formula for P_{MAX} may be of some interest. Figure IV-6(A) is a greatly simplified circuit diagram showing the components that figure in the calculations. Shown are: an input amplifier, followed by a gate circuit, followed by an integrator circuit, and finally, the output meter of the mainframe. Note that the latter—a zero-center milliammeter—is configured so that 10 volts, positive or negative, will send the needle to plus or minus full-scale indication.

Figure IV-6(B) is a graphical representation of the output to the meter during steady-state condition. In other words, a constant-amplitude, full-scale signal is being sampled by the gate for a time t_G. (The formula is valid for *all* signals; the constant-amplitude, full-scale criteria are only for the sake of simplicity in this derivation.) When the gate opens the circuit ($T_{G\text{-}OFF}$), there is a droop of amplitude δ. Each time the gate completes the circuit, the amplitude of the signal once again builds up to the full-scale value. As is normal in boxcar operation, $T_{G\text{-}OFF}$ is much larger than t_G.

(1) During the sampling time, t_G,

$$\Delta E_{OUT} = \delta(1 - e^{-t_G/\tau}) \qquad (1)$$

Where τ is the OTC (or the ATC for AD's shorter than 1 μs).

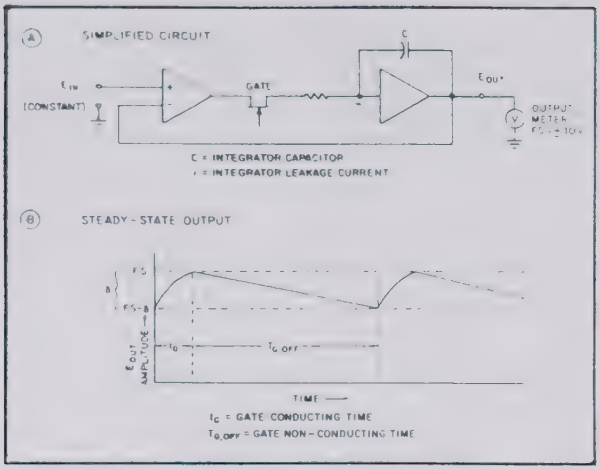


Figure IV-6. P_{MAX} CALCULATIONS

(2) During the "hold" period, T_{G-OFF},

$$\Delta E_{OUT} = \frac{i \times T_{G-OFF}}{C} \qquad (2)$$

Where i is the leakage current of the integrator in amperes, and C is the value of the integrator capacitor in farads.

(3) Since we are interested in the situation where ΔE_{OUT} is the same value in equations (1) and (2), we can set

$$\frac{i \times T_{G-OFF}}{C} = \delta(1 - e^{-t_G/\tau}) \qquad (3)$$

Transposing, we arrive at

$$T_{G-OFF} = \delta C/i \times (1 - e^{-t_G/\tau}) \qquad (4)$$

(4) Since $T_{G-OFF} >> t_G$, the output meter will tend to indicate an average value equal to $\delta/2$. (5)

Also, if full scale on the meter is 10 V, and we desire that $\delta/2$ not exceed an average droop greater than 1% of full scale, then for our computations,

$$\delta = 0.2 \text{ V} \qquad (6)$$

(5) For the average M165, the value of i, the integrator leakage current, may be taken to be

$$i = 4 \times 10^{-12} \text{ A, Maximum} \qquad (7)$$

(6) Substituting equations (6) and (7) in equation (4), we obtain

$$T_{G-OFF} = \frac{C}{2 \times 10^{-11}} (1 - e^{-t_G/\tau}) \qquad (8)$$

Since $T_{G-OFF} >> t_G$, we will not be much amiss in equating P_{MAX}, the maximum trigger period, with T_{G-OFF}. Instead of t_G, we can use its exact equivalent: AD. Making these substitutions, and eliminating the fraction in (8), we arrive at the equation to be derived:

$$P_{MAX} = 5 \times 10^{10} C(1 - e^{-AD/\tau}) \qquad (9)$$

Two assumptions inherent to the use of the formula are that the front-panel BIAS COMP control has been properly adjusted, and that the BASELINE SAMPLING function is "off". If baseline sampling is "on", the allowable P_{MAX} is decreased by a factor of ten. (As noted in the discussion of baseline sampling, not only does the use of this procedure double the OTC, but also there is no provision for zeroing the offset and leakage currents of the baseline-sampling integrator. Consequently, the effects of "droop" are considerably more pronounced when utilizing baseline sampling than when using signal sampling alone.)

Approximate values of P_{MAX} for AD's from 2 ns to 5 ms, and TC's from 0.5 μs to 10 ms may be determined without recourse to the formula by use of the graphs in Figure IV-7. (The graphs take into account ATC, rather than TC, for AD's shorter than 1 μs.)

4.2J SUMMARY: ADR, AD, TC, P_{MAX}, MST

Figure IV-8 brings together many of the factors which must be considered in boxcar operation. In each graph, the horizontal axis represents time; the vertical axis represents amplitude. The former is to scale unless otherwise noted; the latter is definitely *not* to scale. The labeled factors are as follows:

(A) Trigger-amplitude limits are ±0.5 V, Min.; ±100 V, Max.

(B) Minimum trigger duration: 10 ns.

(C) Trigger period (refer to discussion of P_{MAX}).

(D) Trigger delay (minimum time between reception of trigger signal and beginning of ADR): 75-100 ns. Not to scale.

(E) ADR "Jitter" (uncertainty as to beginning of ADR): larger of 50 ps, rms, or .05% of ADR. Not to scale.

(F) ADR-ramp overhang (trigger-insensitive period): 5-10% of ADR.

(G) Trigger-reset time (trigger-insensitive period): 100 ns or 100 μs—the former for ADR's from 100 ns to 50 μs, the latter for ADR's from 100 μs to 50 ms. Not to scale

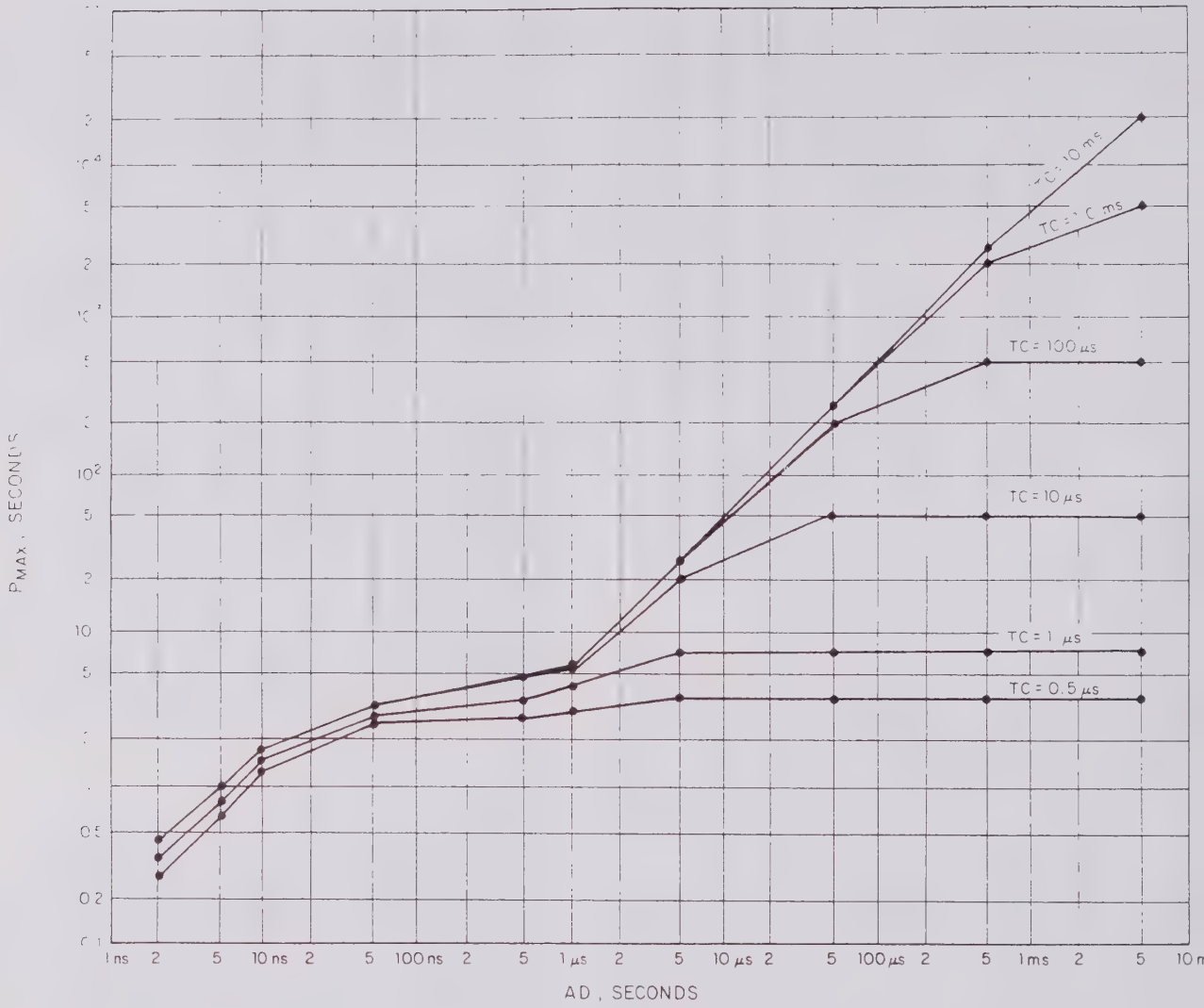


Figure IV-7. P_{MAX} AS A FUNCTION OF TC AND AD

(H) Scan Ramp.

(I) Initial Delay.

(J) Aperture Duration.

(K) Portion of signal being sampled by the respective aperture.

(L) Amplitude of output-voltage increments—determined by TC, as well as by input-signal amplitude, trigger period, and aperture duration.

(M) Droop (see preceding section).

(N) Final amplitude—determined by TC and slope of scan ramp, as well as by input-signal amplitude, trigger period, and aperture duration.

In the operation of any boxcar, occasions will arise when the choices to be made on operating parameters conflict with one another. Following is a brief summary of the more important criteria underlying each choice, and a suggested order of decision making. (Refer to Figure IV-8.)

(1) Aperture Delay Range

Ideally, the ADR should be as short as possible in order to minimize the effects of aperture-delay jitter. Moreover, if the ADR is made too long, the ADR ramp, plus its overhang, may overlap the following trigger. Such overlapped triggers would be ignored by the instrument. (There are times when such overlap may be desirable, however. If the trigger period is shorter than the duration of the waveshape being examined one would *not* want every trigger to initiate a new timing sequence.)

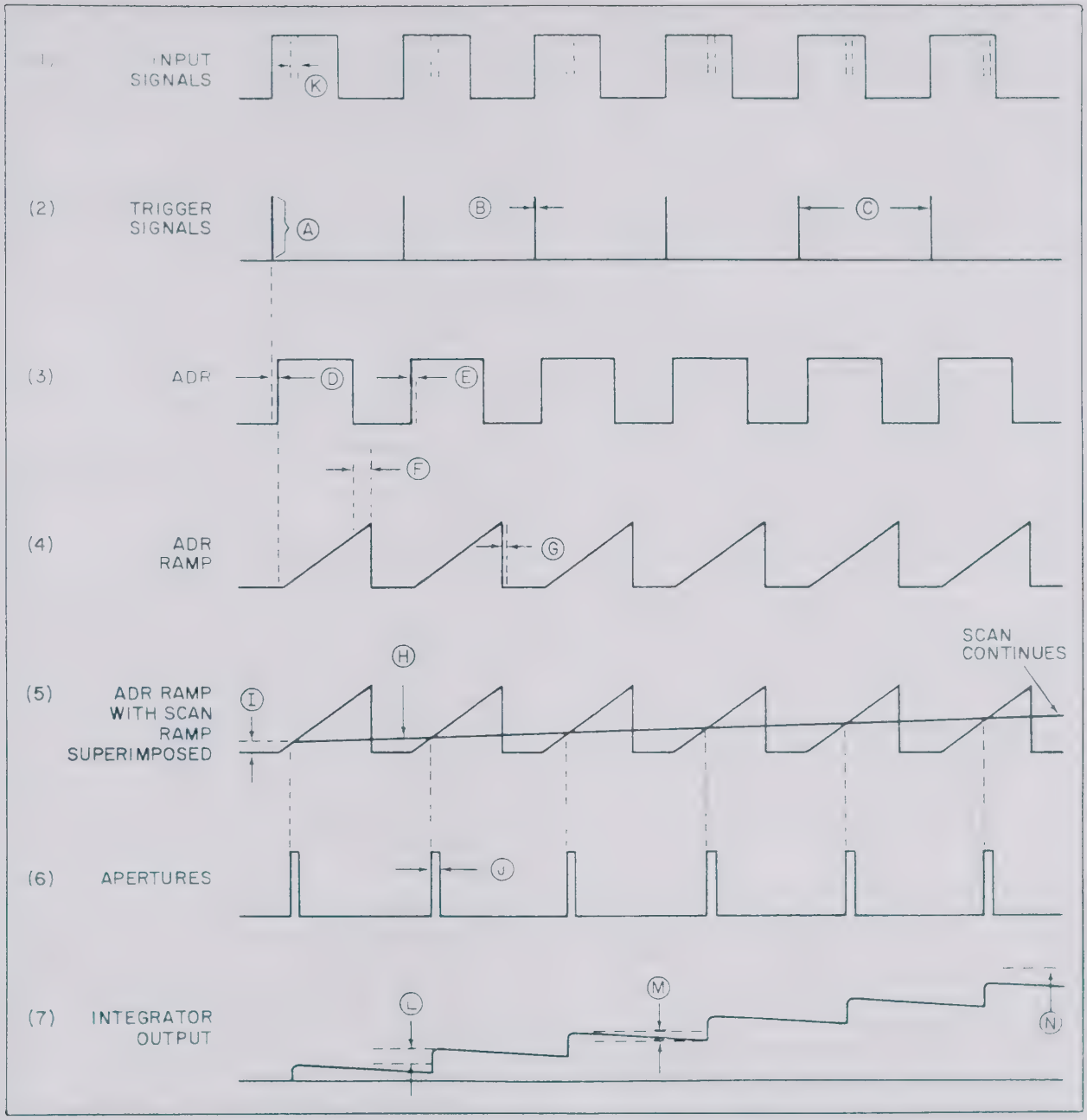


Figure IV-8. IMPORTANT PARAMETERS OF BOXCAR OPERATION

The ADR cannot be too short or it will cause information to be ignored because it falls beyond the end of the ADR interval. In scanned analysis, the ADR must be wide enough so that the entire signal (or that portion of it that is of interest) is analyzed. In single-point or scanned analysis, if the signal portion of interest is located toward the end of the ADR, the measurement time may be shortened by "eliminating" the early part of the ADR ramp by means of the Initial Delay. If the portion of interest is located toward the beginning of the ADR, time can be saved by simply shortening the ADR.

(2) Aperture Duration

In selecting the AD, one must make a compromise between resolution, SNIR, and measurement time. For best results, the AD

should be set according to the resolution desired—remembering that the higher the resolution (i.e., the shorter the AD), the longer it will take to complete a measurement.

(3) Time Constant

In exponential averaging, the TC directly affects the available SNIR. In both exponential and linear averaging, the TC influences the measurement time. The recommended procedure is:

a) In exponential averaging, set the TC according to the SNIR desired, remembering that the longer the TC, the longer it will take to complete a measurement. Frequently it will be possible to use a short TC, but to increase the overall SNIR by means of the mainframe Signal Processing Time Constant—without increasing the measurement time.

(b) In linear averaging, set the TC so that at the end of the analysis the output level will be as large as possible without causing overload. (When the analysis time—AD × N repetitions—equals the TC, the output will be at full scale.)

(4) Trigger Period

With AD and TC determined as above, check that P_{MAX} does not exceed the value determined by its formula (or by Figure IV-7).

(5) Scan Time

For best time-efficiency, the scan-time setting should be no longer than that value determined from the MST formula.

After so many repetitions throughout this manual of the considerations involved in proper settings of the various controls, it may be refreshing now to turn to Figure IV-9, which shows the results of *improper* settings.

For the purpose of these illustrations, a triangular waveshape has been chosen. To make the illustrations even more clear, only the positive-going portions of the waves are utilized. Diagram (1) shows the output from a function generator, the circuit used to clip the negative portions of the waves, and the resulting input to the M165. The horizontal input to the scope is taken from the SCAN IN/OUT jack on the M162 (J9, rear panel); the scope is set for internal triggering. Triggering of the M162 may be taken from the "Sync" output of the function generator or, via an attenuator, from the output signal of the generator. Positive-slope triggering is assumed.

The initial settings of the M162 and M165 are as follows:

Mainframe
% Initial Delay: 10%
Aperture Delay Range: 1 ms
Aperture Duration: 5 μs
Scan Time: 10 s (For the sake of brevity, the Scan Time may be shortened to 1 s in most cases without causing appreciable changes in the displays.)
Time Constant: 0.1 ms
Triggering: External
Function: A
Scan Select: A

Model 165
Time Constant: 1 μs
Aperture-Duration pushbuttons: All released
EXP Averaging
DC Coupled
Sensitivity: 100 mV
Input Impedance: 10 kΩ

Diagram (2) shows the resultant display on the oscilloscope for the given input signal (period = 1 ms) and the given initial settings. Diagrams (3) through (6) show the scope display caused by each "mis-set" control. In these last four sets of diagrams, the "A" diagram is for a control set to a time shorter than the initial setting; the "B" diagrams are for settings longer than in the initial settings. After each "B" diagram, it is assumed that the relevant control is reset to the initial setting before proceeding to the subsequent diagram.

On each diagram, horizontal dotted lines indicate the full-scale amplitude relative to the displays in diagram (2). (In a few places, horizontal dotted lines have been added for the base line as well.) Vertical dotted lines have been extended from the displays in diagram (2) in order to emphasize any time shift.

An elementary analysis of the "improper" signals now follows.

(3A) The ADR is too short relative to the duration of the input signal. Only a portion of the signal has been analyzed. Amplitude has not attained full scale; time shifting has taken place.

(3B) The ADR is too long relative to the signal period. Two signals have been received during each ADR. Resultant signal is time shifted.

(4A) Scan Time too short relative to both the Aperture Duration and the rate of change of the input signal. Resolution is poor.

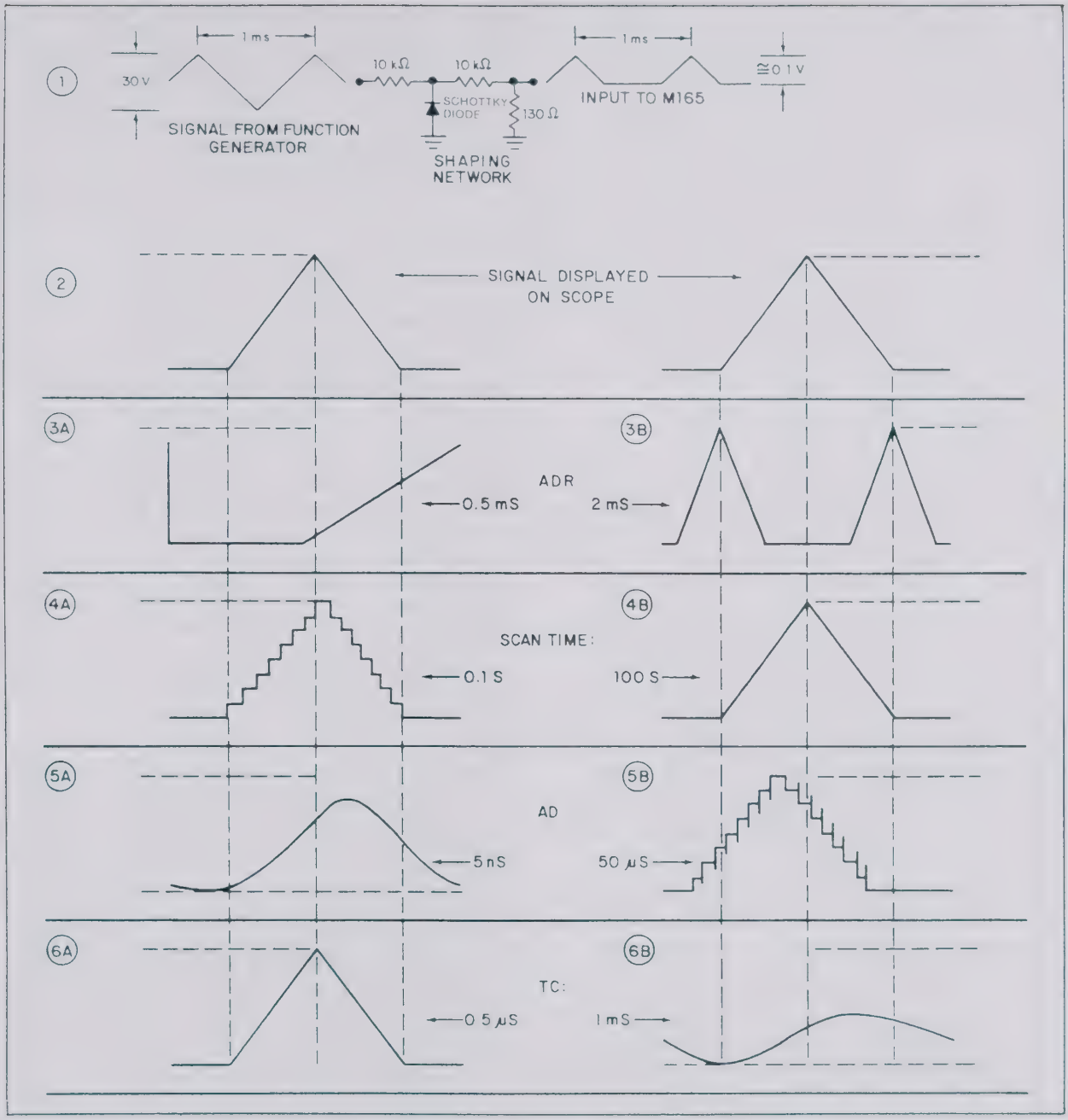


Figure IV-9. 'SCOPE PORTRAYAL OF IMPROPER CONTROL SETTINGS

(4B) Display is perfect, but the time for measurement is excessive.

(5A) The Aperture Duration is too short relative to the Time Constant. The integrator is acting as if it were a low-pass filter. The amplitude does not reach FS; time shifting has occurred.

(5B) The Aperture Duration is much too long relative to the rate of change of the input signal. Resolution is poor, and there is time shifting. (The "spikes" are discussed later.)

(6A) A perfect display, but had there been a noisy background to the input signal, the SNIR with these settings would have been poor.

(6B) The Time Constant is too long relative to the Aperture Duration. As in (5A), the integrator is acting as if it were a low-pass filter. The amplitude does not reach FS; time shifting has occurred

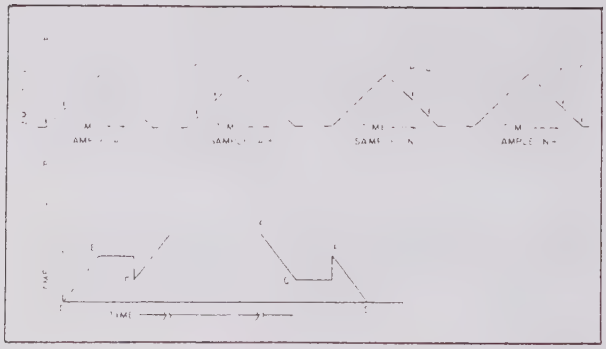


Figure IV-10. ANALYSIS OF FIGURE IV-9 (5B)

The "spikes" in (5B) require some explanation. Figure IV-10A shows one input signal and four samples being taken on it. Points D & E show the duration of one sample; points F & G show the succeeding sample. Points P & Q mark a later sample; points R & S mark the succeeding sample. Figure IV-10B is a simplified version of the output of the integrator following each of these samples. D-E shows the voltage rise during the first sample (any exponential "rounding" has been omitted for the sake of simplicity). At "E", the level holds (droop is ignored). When the next sample is taken, however, the level at instant "F" is lower in amplitude than the holding level from point "E". Then the amplitude rises to point "G". It is the sudden drop from level "E" to level "F" that shows up on the scope as a negative-going spike.

The similar process on the "downward" slope of the input signal results in a positive-going spike from level "Q" to level "R".

4.2K BASELINE SAMPLING

There are two integrators in each Model 165, one for storing signal samples, the other for storing baseline samples. The first is always active, the second only if baseline sampling has been turned on by means of the front-panel BASELINE DELAY control. When this control is fully counterclockwise, baseline sampling is disabled; a signal sample is taken with each repetition, and the output of the Model 165 is the Signal-Integrator output with respect to ground.

In baseline-sampling operation, the sample timing is determined differently on alternate triggers. During each *signal-sampling* cycle (trigger followed by aperture opening timed by mainframe controls) the sample is fed to the Signal-Channel Integrator. During each *baseline-sampling* cycle (trigger followed by aperture opening timed by Baseline-Delay control) the sample is fed to the Baseline-Sampling Integrator.

Assuming exponential averaging, the output of the Signal-Channel Integrator asymptotically approaches the signal level at the point sampled during the signal-sampling cycles. The output of the Baseline-Sampling Integrator asymptotically approaches the level at the point sampled during the baseline-sampling cycles. (It is assumed that the point sampled during baseline sampling is *not* the same point as that sampled during signal-channel sampling). The output of the *module* approaches the *difference* between the two sampled levels.

The *width* of the baseline sample will be equal to the Aperture Duration chosen for the signal sample. The *position* of the baseline sample is determined by the Baseline-Delay control and may be set anywhere throughout the aperture-delay range.

The utility of baseline sampling is that it renders the Model 165 immune to signal-recovery distortion brought about by baseline drift. As the signal voltage rises and falls with the drift, so does the stored baseline voltage, and the difference always accurately represents the absolute signal amplitude independent of drift effects. Baseline sampling even compensates for most of the drifts that arise within the Model 165. The tradeoff one makes in using baseline sampling is one of time. The Observed Time Constant is doubled when baseline sampling is active.

The GATE OUTPUT signal allows precise positioning of the baseline sample through use of an oscilloscope. The oscilloscope should be triggered by the same source as is used to trigger the Model 162 mainframe. If the GATE OUTPUT is then displayed (using a scope sweep-time about equal to the aperture-delay range), two pulses will be observed. One of them marks the signal sample, the other the baseline sample. The former is positioned with the mainframe controls, the latter with the BASELINE DELAY control. The baseline sample varies linearly with the control setting from a few percent of the aperture-delay range to 100% of the aperture-delay range. The two pulses can be easily distinguished; there is a positive spike on the leading edge of the baseline-sample pulse. No such spike is present on the signal pulse. If the signal being measured is displayed simultaneously, both pulses can be optimally positioned.

Use of the baseline-sampling feature is not limited to drift-avoidance applications. The baseline sample could as well be a signal sample, if one were interested in the difference between the levels at two different points on the same waveform. However, the baseline-sampling aperture should not be positioned on a fast edge (leading or trailing), if stable operation is to be assured. The averaging-time constant of the baseline integrator is the same as that of the signal integrator, and the

same SNIR considerations apply. The only limitation on the baseline sample is that there is no provision for scanning its position. Scanning is reserved for the signal sample only. Also, there is no provision for zeroing the offset and leakage current (BIAS COMP. affects signal sampling integrator only), with the result that error from these sources may be larger when operating with the Baseline Sampling ON.

4.2L CHANNEL SYNC. (ALTERNATE CHANNEL TRIGGERING)

The flexibility and power of the Model 165 is extended even further by means of the Channel Sync capability in systems having two Model 165 modules. This function is most useful where two different signals are applied to the input on alternate triggers. Through use of the Channel-Sync function, the first signal can be measured with one of the M165 modules, and the second signal with the other M165. In effect, the two signals are demultiplexed.

To use this function it is necessary to apply a TTL-compatible square wave to the CHANNEL SYNC INPUT of *both* modules. Note that there is a TTL-level-selector toggle switch associated with these inputs. For Channel alternating, these switches must be set oppositely; that is, one switch is set to "1" and the other to "0". It does not matter which switch is set to which position. When the applied square wave is at logic 1, the channel having its TTL selector to "1" will be active. When the applied square wave is at logic 0, the channel having its TTL selector to "0" will be active. (Logic 1 is defined as +3.5 V, ±1 V, and logic 0 as 0.2 V ±0.2 V.) The channel-sync square-wave signal must be synchronized with the triggers. For operation without baseline sampling, the period of the channel-sync square wave should be exactly twice the trigger period (the channel-sync frequency should be half the trigger frequency). For operation with baseline sampling, the period of the channel-sync square wave should be four times the trigger period (the channel-sync frequency should be one-fourth the trigger frequency). In addition, the channel-sync transitions should *lead* the applied triggers by nominally one-half microsecond to prevent ambiguity in the instrument. (The instrument has to be "ready" for a decision *before* the trigger is applied.) These timing relationships are summarized in Figure IV-11.

Alternate-channel triggering is particularly useful for pulsed double-beam systems or experiments in which a sample is alternately stimulated in two different ways. In a two-laser, pump/probe system, for example, the output signal could consist of an alternating "pump only-pump/probe-pump only" sequence. A pair of M165 modules operated in the alternate-channel triggering mode would be ideally suited to such an application, allowing the two signals to be individually measured, or to have their ratio or difference measured.

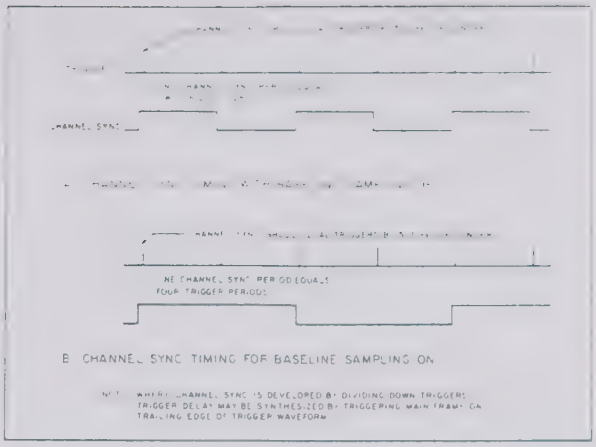


Figure IV-11. CHANNEL-SYNC TIMING

4.2M MATCHING THE DIGITAL-STORAGE OPTION TO THE MODEL 165

Although memory units employed in signal-channel modules are designed to provide maximum memory retention, there is inevitable leakage (discussed earlier under "Droop"). Normally, leakage is insignificant, but in certain applications—involving both low repetition rates and narrow aperture durations—memory leakage can degrade output accuracy. This problem may be alleviated by the installation (in the mainframe) of the Digital-Storage Option card 162/99. Refer to the M162 manual for a description of this option.

If a Digital-Storage Option is installed in the mainframe, it must be aligned to match the M165 module with which it is to be used.

The following procedure sets the zero and gain for Digital Storage in both the A and B channels. Four adjustments are involved; the others should be left undisturbed. This procedure should be used whenever it is necessary to match the Digital Storage Option to a module. Once matched to a given module operating in a given channel, the adjustments need not be disturbed again, except possibly as part of a regular maintenance program. However, if any other module is to be operated in the same channel, with the digital storage turned on, the alignment will have to be repeated for that channel if proper operation is to be obtained.

WARNING!

POTENTIALLY LETHAL VOLTAGES ARE PRESENT INSIDE THIS APPARATUS. THESE SERVICE INSTRUCTIONS ARE FOR USE BY QUALIFIED

PERSONNEL ONLY. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY SERVICING UNLESS YOU ARE QUALIFIED TO DO SO. ANY ADJUSTMENT, MAINTENANCE, AND REPAIR OF THE OPENED APPARATUS UNDER VOLTAGE SHALL BE AVOIDED AS FAR AS POSSIBLE AND, IF UNAVOIDABLE, SHALL BE CARRIED OUT ONLY BY A SKILLED PERSON WHO IS EXPERIENCED IN WORKING ON ELECTRONIC APPARATUS AND WHO IS AWARE OF THE HAZARD INVOLVED. WHEN THE INSTRUMENT IS CONNECTED TO A POWER SOURCE, TERMINALS MAY BE LIVE, AND THE OPENING OF COVERS OR REMOVAL OF PARTS IS LIKELY TO EXPOSE LIVE PARTS. THE APPARATUS SHALL BE DISCONNECTED FROM ALL VOLTAGE SOURCES BEFORE IT IS OPENED FOR ANY ADJUSTMENT, REPLACEMENT, MAINTENANCE, OR REPAIR. CAPACITORS INSIDE THE UNIT MAY STILL BE CHARGED EVEN IF THE UNIT HAS BEEN DISCONNECTED FROM ALL VOLTAGE SOURCES. USERS ARE ADVISED TO WAIT SEVERAL MINUTES BEFORE ASSUMING THE CAPACITORS ARE DISCHARGED.

(1) Preliminary Steps

(a) Plug in the line cord, turn on the power, and allow a half-hour warmup. **NOTE:** The assumption is made that the modules to which the Digital Storage Option is to be matched have been installed. If there is but one module, place it in the Channel A position and do the Channel A adjustments only. The Channel B adjustments can be performed later if a second module becomes available.

(b) Set the mainframe controls as follows.

Aperture Delay
% Initial A: 10%
% Initial B: 10%
Aperture Duration: 5 μSEC and CAL
Scan Time: setting immaterial
Scan Select pushbuttons: EXT depressed; all others released
Trigger Mode pushbuttons: LINE depressed; all others released
Trigger Level: Adjust for proper triggering as indicated by steady glow of TRIGGERED light
Function switch
Outer knob: A
Inner knob: DIG. STORAGE ON
Time Constant: 0.1 mSEC.

(c) Set the controls of M165 module(s) as follows.

Time Constant: 0,5 μs
Aperture: all pushbuttons released
Other pushbuttons:
EXP/SUM depressed
DC/AC depressed
10 kΩ/50 Ω released
CAL released
Baseline Delay: Off
Sensitivity: Zero Check position

(2) Zero Adjustments (Figure IV-12)

(a) Set the Channel A module's ZERO control for "0" panel-meter indication.

(b) Connect the oscilloscope to the Channel A module's AVG OUT BNC. The scope sensitivity should be 10 mV/cm, and the sweep rate should be 2 ms/cm. The scope should be LINE triggered and dc coupled.

(c) Set the CHANNEL A ZERO adjustment (Dig. Storage Option board) for minimum pedestals in the oscilloscope display.

(d) Set the mainframe FUNCTION switch to B. Then adjust the Channel B module's ZERO control for "0" panel-meter indication.

(e) Connect the scope to the Channel B module's AVG. OUT BNC. Set the CHANNEL B ZERO adjustment (Dig. Storage Option board) for minimum pedestals in the oscilloscope display.

(f) Set the FUNCTION switch back to A and go on to step 3.

(3) Gain Adjustments (Figure IV-12)

(a) Change the scope to ac coupling.

(b) Turn the Digital Storage OFF (inner knob of FUNCTION switch).

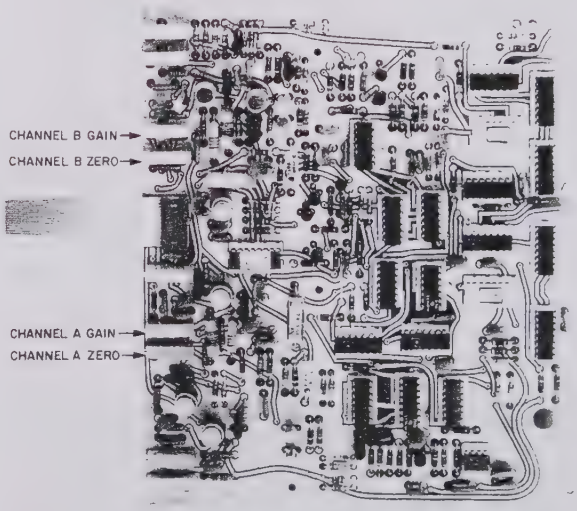


Figure IV-12. DIGITAL-STORAGE ZERO AND GAIN ADJUSTMENTS

(c) Depress the CAL pushbutton on the Model 165 in Channel A and set the Sensitivity switch to the 5 V position. Then set the CAL ADJ. to obtain a full-scale panel-meter indication.

(d) Turn the Digital Storage Option ON (inner knob of FUNCTION switch).

(e) Connect the scope to the Channel A module's AVG. OUT BNC. Set the CHANNEL A GAIN adjustment (Dig. Storage Option board) for minimum pedestals in the oscilloscope display.

(f) Set the FUNCTION switch to B and turn the Digital Storage OFF (inner knob of FUNCTION switch).

(g) Depress the CAL pushbutton on the Model 165 in Channel B and set the Sensitivity switch to the 5 V position. Then set the CAL. ADJ. to obtain full-scale panel-meter indication.

(h) Turn the Digital Storage Option back ON.

(i) Connect the scope to the Channel B module's AVG. OUT BNC. Set the CHANNEL B GAIN adjustment (Dig. Storage Option board) for minimum pedestals in the oscilloscope display.

(4) Final Checks

(a) The panel-meter indication at this point should be full scale. Press in the EXT Trigger Mode pushbutton. The panel-meter indication should not change.

(b) Set the FUNCTION switch back to A. The panel-meter indication should be full scale.

(c) Release the CAL pushbuttons on both modules and set the Sensitivity switches to the Zero-Check positions.

(d) Depress the LINE Trigger-Mode pushbutton. Then vary the Channel B module's ZERO control over its entire range. The output indication should smoothly track the ZERO-Control setting.

(e) Set the FUNCTION switch to A. Then repeat the Zero-Control check described in the previous steps, this time using the Channel A Processor Module ZERO control.

THIS COMPLETES THE ALIGNMENT STEPS NECESSARY TO MATCH THE DIGITAL STORAGE OPTION TO THE PROCESSOR MODULES WITH WHICH IT IS TO BE USED. NOTE THAT IN EVERY APPLICATION REQUIRING DIGITAL STORAGE, THE MODULES WILL HAVE TO BE OPERATED IN THE SAME POSITION AS FOR THE PRECEDING ALIGNMENT. IF A DIFFERENT MODULE IS USED, THE ALIGNMENT WILL HAVE TO BE REPEATED WITH THAT MODULE.

SECTION V
ALIGNMENT

WARNING!

PRECAUTIONS WITH RESPECT TO POTENTIALLY LETHAL VOLTAGES APPLY WHENEVER THE COVER IS REMOVED FROM THE MODEL 165. BEFORE PROCEEDING, THE USER MUST READ AND OBSERVE THE CAUTION NOTICE RELATING TO THE INSTALLATION OF THE DIGITAL STORAGE OPTION, LOCATED ON PAGE IV-17.

5.1 INTRODUCTION

Even though the M165 is conservatively designed, alignment may be advisable after long usage for continued high confidence in measurement data obtained with the system. In addition, should instrument repair ever be necessary, alignment after the repair is recommended.

Although alignment of the M165 requires no internal adjustments to the M162 mainframe, it is essential that the mainframe be in proper operating condition in order for one to align the M165.

We suggest that the following adjustments be made in the indicated sequence, and that any decision to eliminate steps be reserved to someone having sufficient knowledge of the circuitry to understand fully all possible interactions.

It may be noticed during this alignment procedure that some of the internal controls in the M165 are not mentioned. Do NOT adjust any internal controls not specifically mentioned in the procedure. Invariably their proper settings require special test equipment not available in the field.

Note also that this alignment procedure is not intended for troubleshooting. If the instrument is suspected of malfunctioning, go directly to Section VI, which describes methods for isolating faulty circuits. (Naturally, the M165 must be trouble-free before it can be aligned.)

5.2 EQUIPMENT REQUIRED

(1) M162 mainframe, and extender cables 6020-0093-19 and 6020-0098-14.

(2) Dual-trace oscilloscope with dc-100 MHz bandwidth; sensitivity at least 50 mV/cm.

(3) Square-wave generator capable of supplying 100 Hz and 10 kHz signals at 1 V. pk-pk.

(4) Digital Voltmeter (DVM), with ± 1 mV resolution.

5.3 PRELIMINARY STEPS

CAUTION!

IN THE ALIGNMENT PROCEDURE, THE USER IS INSTRUCTED OCCASIONALLY TO "GROUND" A TEST POINT. BEFORE DOING SO, ALWAYS MAKE CERTAIN THAT IT IS THE CORRECT TEST POINT YOU ARE GROUNDING. IF AN *OUTPUT* TEST POINT IS GROUNDED, COMPONENTS IN THE CIRCUIT MAY BE DAMAGED.

(1) Turn off power on the M162 mainframe.

(2) Remove the M165 module. Place it on a workbench with the front panel to your left, and the row of pushbuttons down. Remove the two screws (one on the front panel and one on the rear) normally securing the panels to the ends of the top rail nearest you. Then *loosen* the two screws similarly securing the front and rear panels to the top rail away from you. Swing the printed-circuit board up and toward the rear. **CAUTION:** Do not force the board down to the work surface; prop it up more or less level with the top edge of the module.

Remove the two screws at the top of the small, "piggy-back", printed-circuit board which fasten it to the underside of the larger board. The smaller board is hinged, and may now be swung down so that adjustments may be made on the larger board.

(3) Use the extender cables to connect the M165 to the mainframe.

(4) Turn on the mainframe power and allow a half-hour warm up.

5.4 POWER-SUPPLY ADJUSTMENTS

(1) Connect the DVM between the chassis and the lower-rear contact on the CAL pushbutton switch (i.e., the last contact on the right in the row nearest you).

(2) Refer to Figure V-1 to locate R98 on the A.T. Gate Gen/Logic board. Depress the CAL pushbutton and adjust R98 in order to obtain + 5.000 ± 50 mV on the DVM. Release the CAL pushbutton.

5.5 HIGH-IMPEDANCE-BUFFER ADJUSTMENT

(1 Release all Scan-Select and Trigger-Mode pushbuttons on the M162. The position of all other M162 controls is immaterial

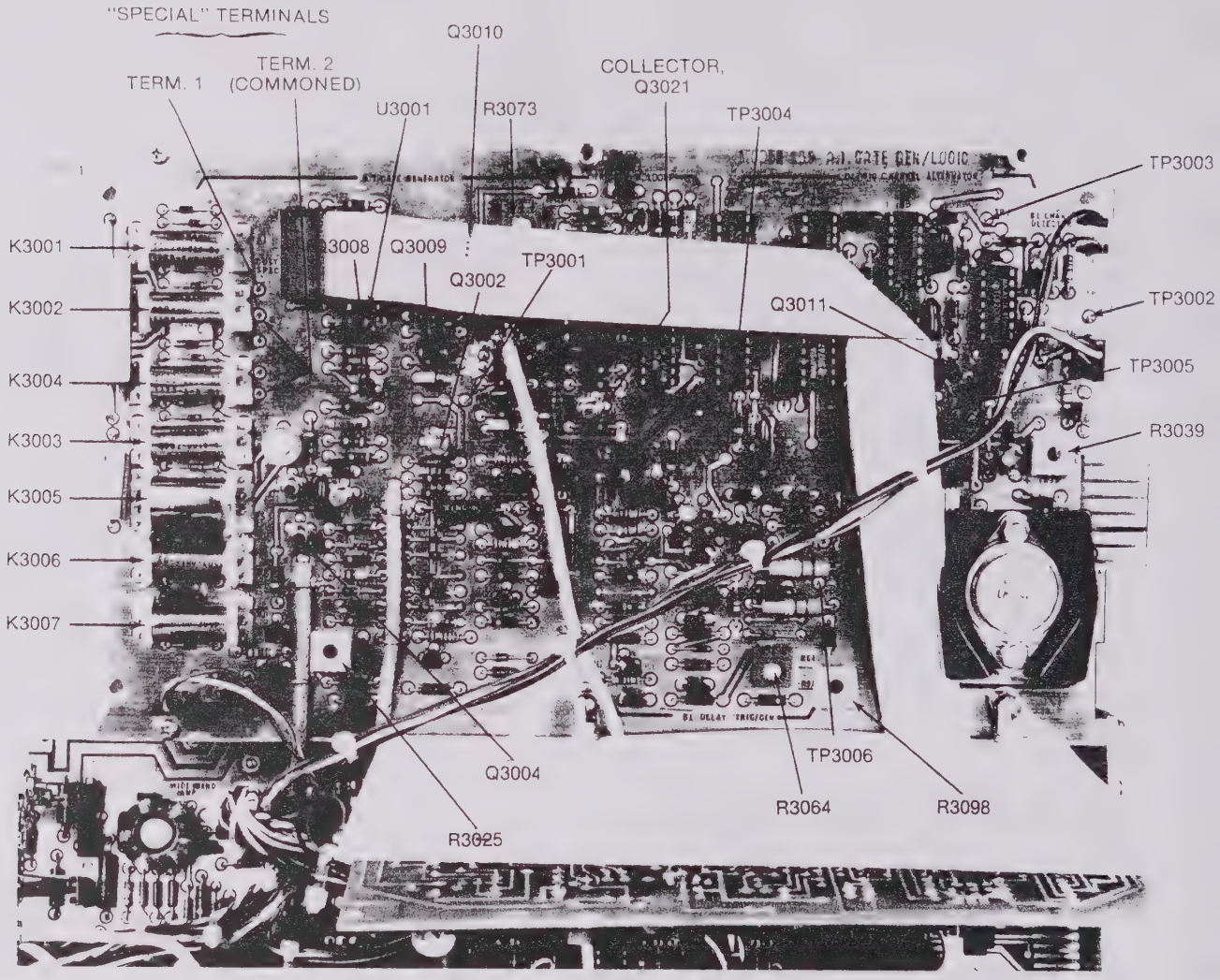


Figure V-1. A.T. GATE GENERATOR/LOGIC BOARD

(2) Set the front-panel controls on the M165 as follows:

10 kΩ/50 Ω pushbutton: Depressed
All other pushbuttons: Released
Sensitivity: Zero-Check position
All other settings: Immaterial

(3) Connect the DVM to TP1 on the Sampling Board (see Figure V-2). Adjust R10 for a reading of 0.000 V ±1 mV. **CAUTION:** Accidental grounding of TP1 will damage U1.

5.6 WIDE-BAND AMPLIFIER (Ignore erratic action of the M162's panel meter during this adjustment)

(1) Disconnect J24 from the Sampling board, and set the front-panel controls on the M165 as follows:

Pushbutton switches: AC/DC depressed; all others released
All others: Immaterial

(2) Set the Sensitivity switch to the Zero-Check position.

(3) Connect the DVM to TP2 and adjust R32 for a reading of 0.000 V ±5 mV.

(4) Disconnect the DVM; leave J24 disconnected until procedure 5.12(4) is completed.

5.7 A.T. GATE GENERATOR

(1) On the M162, set the AD to 0.5 μs, and the ADR to 5 μs; depress the EXT TRIGGER pushbutton. From the square-wave generator supply a 10 kHz, 1 V pk-pk signal to the Trigger Input of the M162.

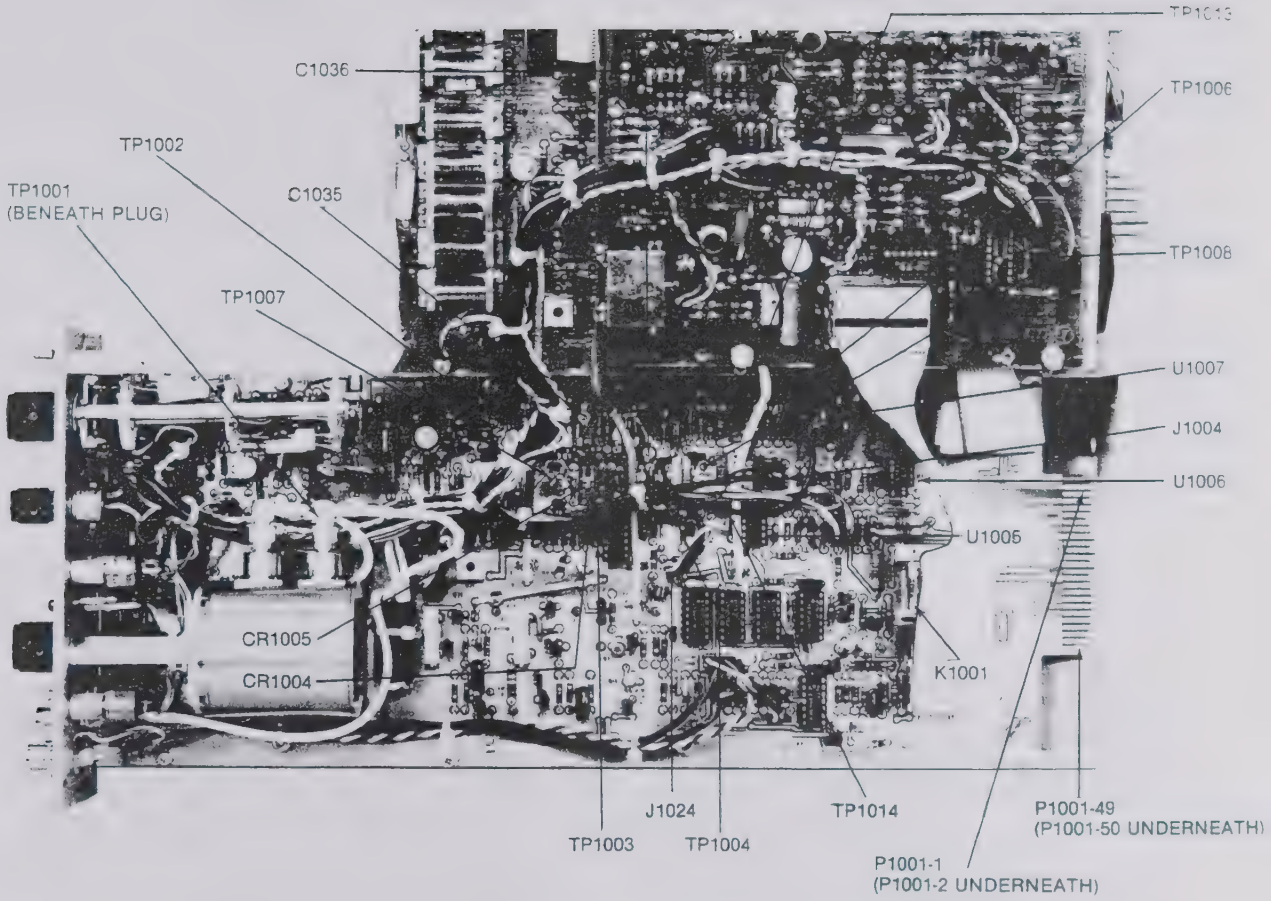


Figure V-2. SAMPLING BOARD (FOR RESISTANCE ADJUSTMENTS SEE FIGURE V-7)

(2) Set the Gate-Trim adjustment (screwdriver setting, front panel of the M165) to mid-range; release all Aperture pushbuttons.

(3) Set the scope as follows:

DC coupled
Vertical Sensitivity: 2 V/cm
Time Base: 0.1 μs/cm

Trigger the scope with the same 10 kHz signal being supplied to the M162, and monitor TP7 on the Sampling board.

(4) Adjust R25 on the A.T. Gate Gen/Logic board so that the observed pulse width at the zero crossing is 0.5 μs. See Figure V-3.

5.8 SAMPLE-AND-HOLD CIRCUIT ADJUSTMENT (SAMPLING BOARD)

1) Release the EXT TRIG pushbutton on the M162.

(2) Ground the normally ungrounded end of R103 (300 kΩ). In later production models, this end of R103 is also TP13.

(3) Connect the DVM to TP6, then adjust R80 to obtain a reading of 0.000 V ± 1 mV.

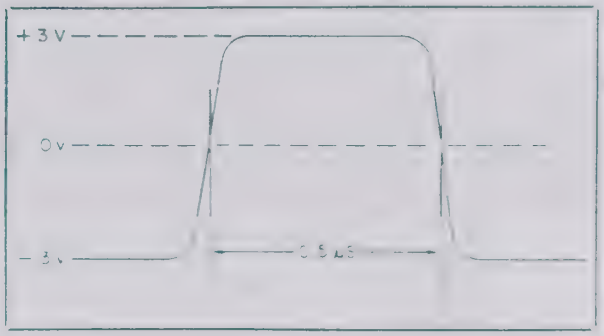


Figure V-3. A.T. GATE GENERATOR PULSE ALIGNMENT

(4) Remove the ground from R103 (or TP13).

(5) With the DVM still connected to TP6, adjust R75 for 0.000 V ± 1 mV.

5.9 SIGNAL-CHANNEL INTEGRATOR (INTEGRATOR BOARD)

ZERO ADJUSTMENT

(1) Disconnect J6 from the Integrator board (see Figure V-4).

(2) Ground TP1, and connect the DVM to TP2.

(3) Adjust R14 until the voltage at TP2 changes polarity—an abrupt transition. After the polarity change, slowly turn R14 in the opposite direction until the meter just flips back to the original polarity.

BIAS COMPENSATION

(1) Disconnect the ground from TP1, but leave J6 disconnected, and leave the DVM connected to TP2. (Since the following test involves judging a rate of change of voltage, an analog voltmeter may be preferable.)

(2) Momentarily depress the M165 Clear button and watch the voltmeter. After returning to zero, the meter will indicate a drift in either the positive or the negative direction.

(3) Adjust the Bias Comp control (front-panel screwdriver adjustment) until the drift *rate* is minimum. The drift rate should be less than one volt per second, meaning that the meter should take longer than ten seconds to drift ten volts. Depress the Clear button as often as necessary to set the Bias Comp properly.

(4) Remove the DVM from TP2. Reconnect J6.

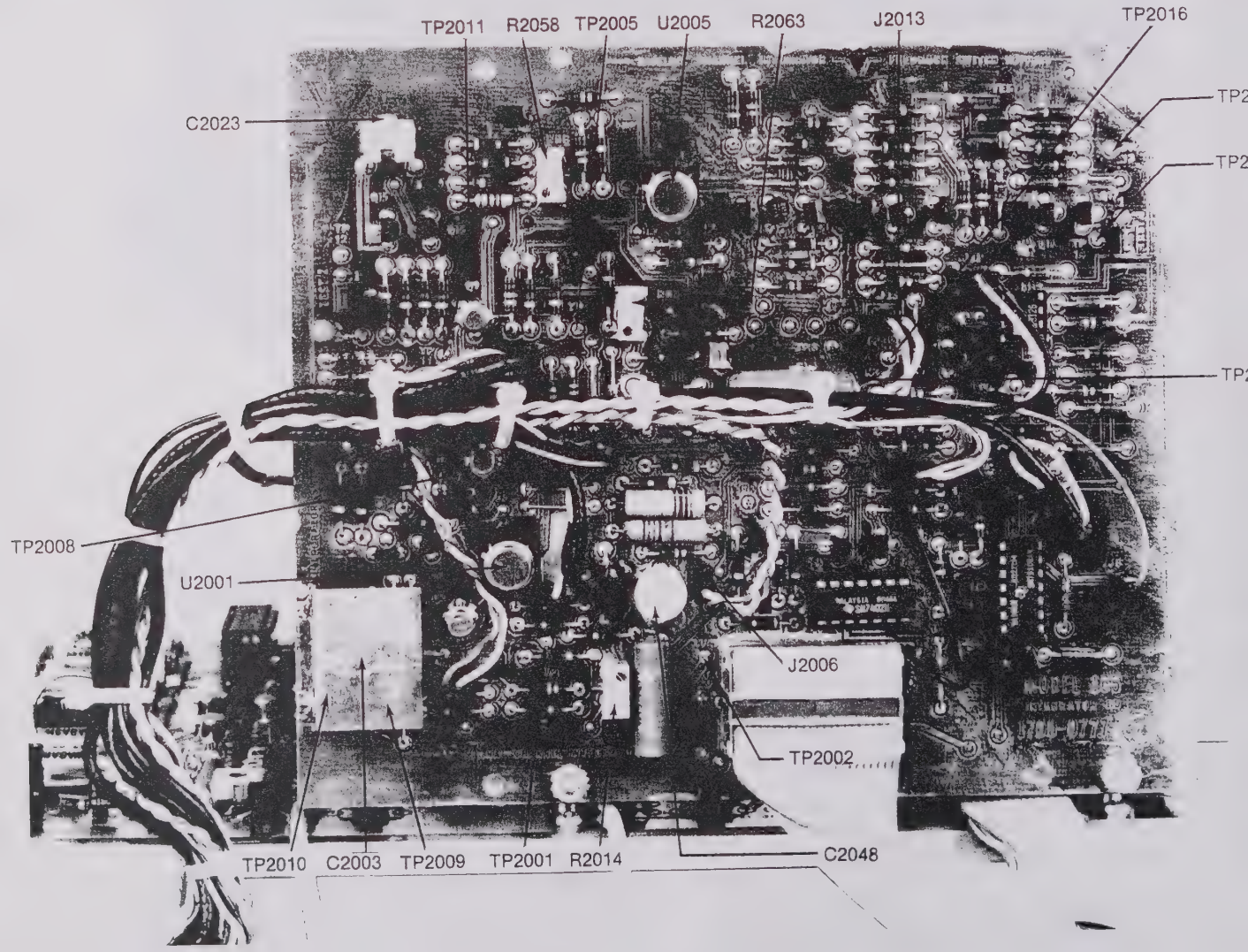


Figure V-4. INTEGRATOR BOARD

5.10 BASELINE-CHANNEL INTEGRATOR (INTEGRATOR-BOARD)

ZERO ADJUSTMENT

(1) Disconnect J13 and ground TP5.

(2) Connect the voltmeter to TP6. Adjust R63 until the voltage at TP6 abruptly reverses polarity. Then slowly turn the control in the opposite direction until the meter just switches back to the original polarity.

BIAS COMPENSATION

(1) Disconnect the ground from TP5, but leave the voltmeter connected to TP6. Again, the following test requires judgment of the rate of change of a voltage, so an analog meter may be desirable.

(2) Momentarily depress the Clear pushbutton and watch the voltmeter. After returning to zero it will drift in either the positive or the negative direction.

(3) Adjust R58 until the drift rate is minimum. It should be less than one volt per second, so the meter should take more than ten seconds to drift ten volts. Depress the Clear pushbutton as often as necessary to set R58 properly.

(4) Disconnect the voltmeter from TP6 and reconnect J13.

5.11 BASELINE/SIGNAL-CHANNEL ADJUSTMENTS (A.T. GATE-GEN/LOGIC BOARD)

(1) Set the M162 front-panel controls as follows:

Initial A & B: 3%
ADR: 20 μs
AD: 5 ns
Time Constant: 0.1 ms and CAL
Scan Select: All pushbuttons released
Trigger Mode: EXT, Positive slope

(2) Trigger the M162 with 10 kHz square waves.

(3) Set the Baseline Delay control on the M165 fully clockwise.

(4) Monitor TP2 with the DVM, and adjust R39 for a reading of 4.500 V $\pm$ 10 mV.

BASELINE-DELAY TRIGGER GENERATOR

(1) With the DVM still connected to TP2, adjust the M165's Baseline-Delay control to obtain a reading of 2.25 V $\pm$ 10 mV.

(2) Set the scope as follows:

Vertical Sensitivity: 1 V/cm
Time Base: 5 μs/cm
Trigger Mode: External, dc-coupled, negative slope
Input Coupling: DC

(3) Trigger the scope on the negative-going edge of the Delay-Range-Frame signal appearing at TP5 (see Figure V-5A). Connect one probe of the scope to TP5 and the other probe (the probe for the second trace) to TP4. Adjust R64 until the negative-going edge at TP4 occurs 10 μs $\pm$ 0.2 μs after the negative-going edge at TP5 (see Figure V-5B).

(4) Remove the two scope-signal probes, but leave the scope-trigger connection. Turn off the Baseline control.

TRIGGER HOLD-OFF

(1) Depress any one of the AD pushbuttons on the M165.

(2) Connect the scope to the collector of Q21 and change the scope's trigger slope to Positive. Adjust the triggering level of the scope to make it trigger on the positive-going edge of the Delay-Range-Frame signal appearing at TP5.

(3) Adjust R73 to set the logic "0" gating pulse at Q21's collector to 50 μs (see Figure V-5C).

5.12 FEEDBACK AMPLIFIER, ZERO ADJUSTMENT (SAMPLING BOARD)

(1) Ground pin 2 of U5. (In later models, TP14. With earlier models without TP14, it may be wise to turn off mainframe power before attempting to connect to, or disconnect from, pin 2 of U5.)

(2) Disconnect J4.

(3) Adjust R49 until a polarity change is observed on the DVM. When that happens, slowly turn the control in the opposite direction until the polarity just reverses again.

(4) Remove the ground from pin 2 of U5 (or TP14), disconnect the DVM from TP5, reconnect J4, and reconnect J24.

5.13 OUTPUT AMPLIFIER

ZERO ADJUSTMENT

(1) Connect the DVM to the AVG OUT BNC of the M165

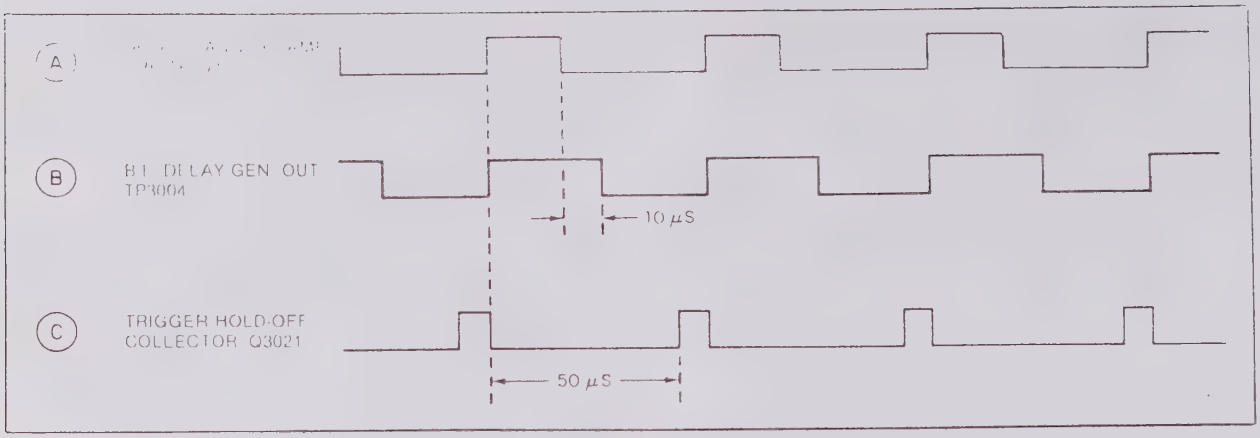


Figure V-5. DELAY-RANGE-FRAME TIMING DIAGRAMS

(2) Adjust R63 on the Sampling board, while depressing the M165's Clear pushbutton, to obtain a DVM reading of 0.000 ± 10 mV.

COMMON-MODE ADJUSTMENT

(1) Set the Sensitivity control on the M165 to 5 V. Turn the Baseline "on", and depress the CAL pushbutton.

(2) Connect the DVM differentially (floating) to both TP2 and TP6 of the Integrator board. Adjust the M165's Zero control for a reading of 0.000 V ± 25 mV on the DVM.

(3) Connect the DVM to the M165's AVG OUT BNC. Adjust R61 (Sampling board) for a reading of 0.000 V ± 25 mV to ground.

SIGNAL-CHANNEL GAIN

(1) Set the Baseline "off". Set the Sensitivity control to the ZERO CHECK position. Re-zero the DVM by adjustment of the front-panel Zero control on the M165.

(2) Set the Sensitivity control to 5 V. Adjust the M165's CAL control (front-panel screwdriver adjustment) for − 10.000 V ± 25 mV at the AVG OUT BNC.

BASELINE-CHANNEL GAIN

(1) Set the Baseline "on". Set the Sensitivity switch to ZERO CHECK. Re-zero the DVM by means of the front-panel zero control. Then set the Sensitivity switch to 5 V.

(2) Adjust R56 on the Sampling board for 0.000 V ± 25 mV at the AVG OUT BNC. Release the CAL pushbutton.

5.14 CHARGE-PUMP COMPENSATION

PRESETS

(1) On the M162, set the ADR to 20 μs; set the AD to 5 μs. All Scan Select pushbuttons should be released. Apply a 10 kHz square-wave trigger input.

(2) On the M165, release all AD pushbuttons.

(3) Set up the oscilloscope as follows:

Coupling: AC
Triggering: External. Trigger with the 10 kHz square waves.
Sensitivity: 50 mV/cm
Sweep Rate: 5 μs/cm

SIGNAL-CHANNEL ADJUSTMENTS

(1) Connect the input of the scope to TP2 on the Integrator board. A "× 1" probe is acceptable.

(2) If this circuit is *out of alignment*, a rectangular pulse, 5 μs wide, will appear on the scope. Both the polarity and the amplitude of the pulse depend upon the setting of C3. See Figure V-6A & B for possible traces. The goal is to reduce the amplitude of the pulse by adjusting C3 until most of the pulse is coincident with the baseline. See Figure V-6C for a typical adjusted trace. Deviation from the baseline—in either direction—must not exceed 20 mV.

BASELINE-CHANNEL ADJUSTMENTS

(1) Set the Baseline Delay control to its mid-range position.

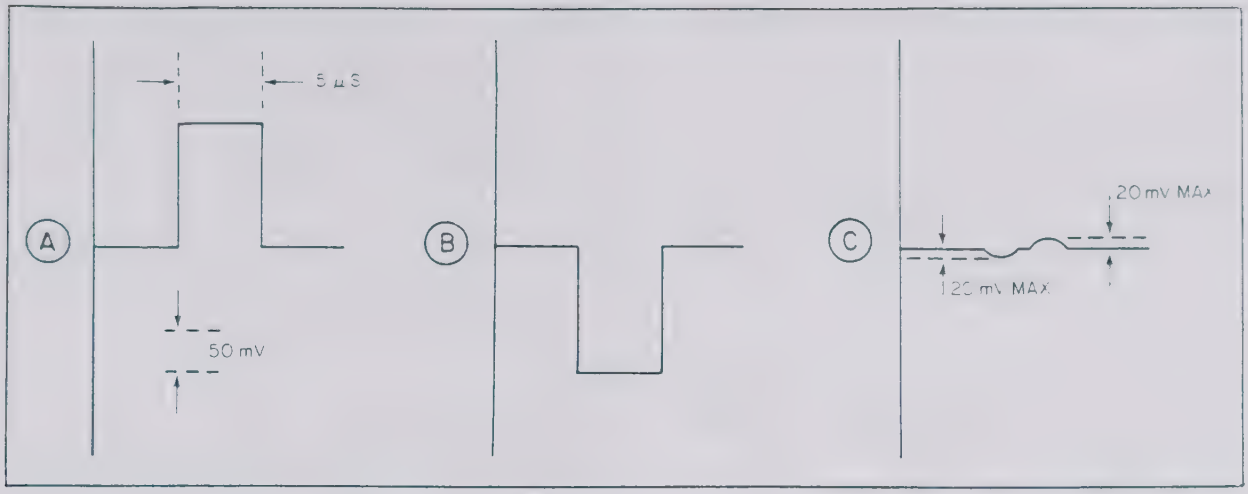


Figure V-6. CHARGE-PUMP COMPENSATION: SIGNAL-CHANNEL ADJUSTMENTS

(2) Connect the scope to TP6 on the Integrator board. A rectangular pulse will be observed again. Repeat the above-mentioned procedure on this trace, but this time use C23 to minimize the pulse height. Once more, the deviation from the baseline in either direction must not exceed 20 mV.

5.15 FINE-LOOP ZERO

PRESETS

(1) Leave the M162 set as above.

(2) On the M165, the EXP/SUM and AC/DC push-buttons should be depressed. Set the Sensi-

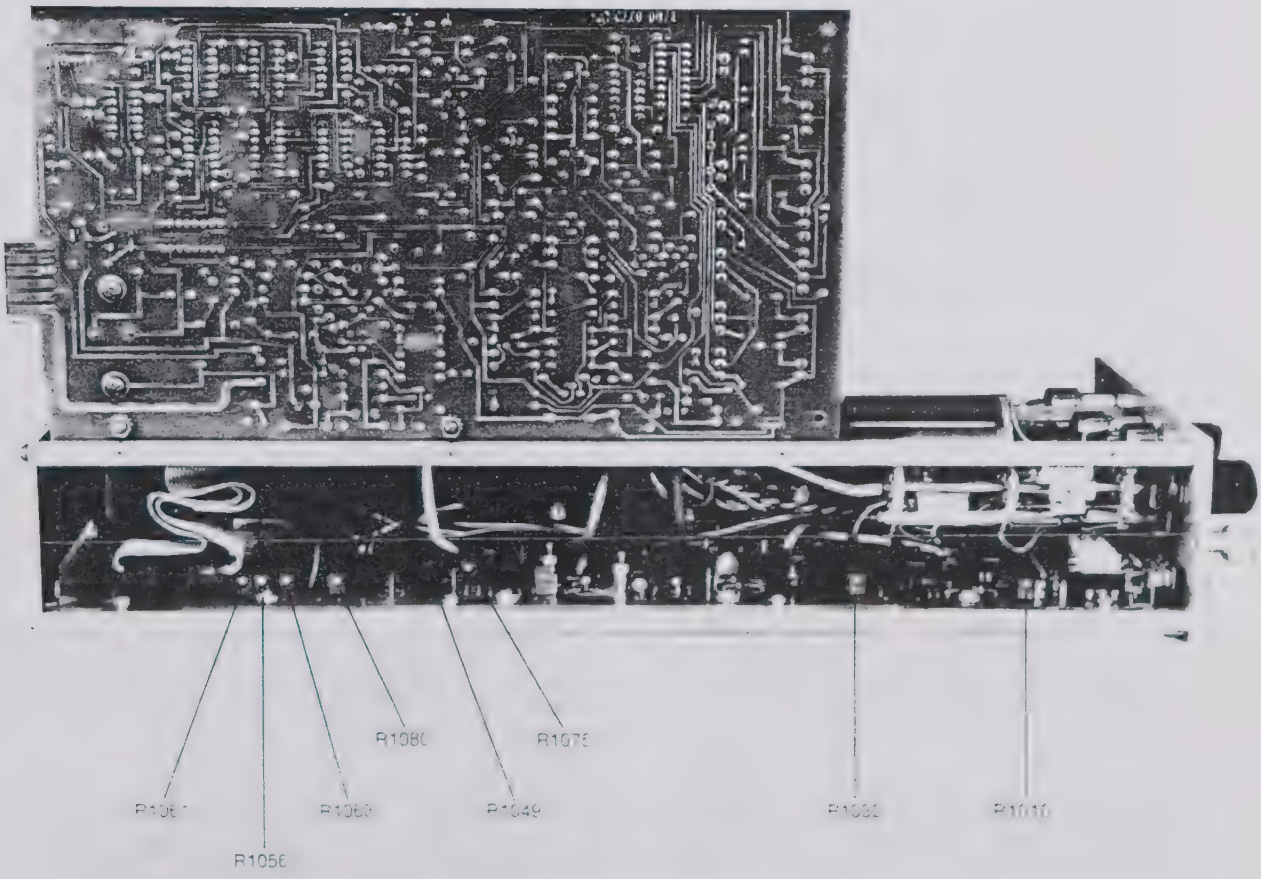


Figure V-7. SAMPLING BOARD, SIDE VIEW

tivity to ZERO CHECK; set the Baseline Delay "off".

ZERO ADJUSTMENT

(1) Remove J4 from the Sampling board.

(2) On the Sampling board, adjust R32 for a reading on the M162's meter of 0.000 V ± 100 mV.

(3) Reconnect J4.

5.16 SAMPLING-GATE COMPENSATION (SAMPLING BOARD)

(1) Keep all presets as above. If necessary, use the Zero control on the M165 to bring the M162's meter to a zero indication.

(2) While observing the M162's meter, depress in turn the 15 ns, 10 ns, 5 ns, and 2 ns AD pushbuttons on the M165. Most likely, the meter reading will depart from zero as the pushbuttons are depressed. The object of this alignment procedure is to minimize these departures from zero.

(3) Make a mental note of the average of the departures from zero caused by the three larger AD's. Then depress the 2 ns pushbutton and adjust R75 to bring the departure from zero of the 2 ns AD approximately to the average of the other three. If the maximum variation from zero of *any* AD is now no more than ± 1 V, this portion of the alignment may be considered complete. If the above procedure still leaves one or more of the departures from zero more than one volt positive or negative, proceed to step (4).

(4) Adjust both trimming capacitors C35 and C36 so that their threaded shafts are approximately at the mid-point of their travel.

(5) These capacitors work in opposition to one another: one will decrease the departure from zero as its capacitance is increased (i.e., as the threaded shaft is screwed into the body); the other capacitor will decrease the departure as the shaft is screwed out of the body. Find the capacitor—by trial and error—which decreases the AD's departures from zero as the threaded shaft is screwed *out* (that is, as its capacitance is reduced).

(6) Keep unscrewing the shaft of this capacitor—in short steps—while checking all of the AD's. If all departures from zero are brought below ± 1 V with this adjustment, this part of the alignment is complete.

(7) If the above procedure still has not brought success, and the threaded shaft is approaching the end of its travel (in other words, only a few threads are still holding into the body), then transfer activity to the other capacitor and begin screwing its shaft *into* the body in short steps.

(8) If this last adjustment still has not obtained the desired result by the time the shaft is screwed all the way "in", consult with the factory.

5.17 STORE-GATE COMPENSATION

(1) Reset the ADR on the M162 to 5 ms; leave the AD at 5 μs. Turn "on" the DIGITAL OPTION; however, if a Digital-Option board is actually installed in the M162, unplug its ribbon cable.

(2) Reset the scope as follows:

Vertical Sensitivity: 50 mV. A "× 1" probe is acceptable.
Time Base: 2 ms/cm
Coupling: DC

(3) Change the square-wave generator's setting to 100 Hz and apply this signal to the trigger inputs of both the M162 and the scope.

(4) Connect the scope input to the AVG OUT connector on the M165.

(5) Readjust the Zero control on the M165 to get the M162 panel meter as close to a zero reading as possible.

(6) The display on the scope should resemble Figure V-8. If the "zero" setting on the M165 is slightly on the positive side, the trace will be as shown. If the "zero" is slightly on the negative side, the large rectangular portion of the display will be negative-going.

(7) Adjust C48 on the Integrator board until the *small* pedestal is as close to zero amplitude as possible. A 20 mV pedestal is the maximum acceptable.

(8) Turn the DIGITAL OPTION "off", disconnect the scope from the M165, turn off mainframe power and, if it had been disconnected, reconnect the ribbon cable on the Digital Option board.

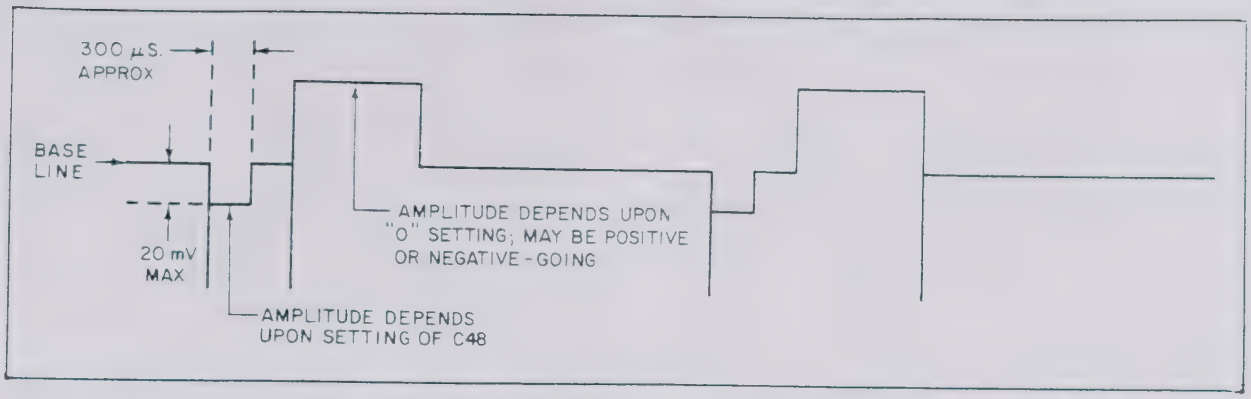


Figure V-8. STORE-GATE COMPENSATION ADJUSTMENT

SECTION VI
TROUBLESHOOTING

WARNING!
PRECAUTIONS WITH RESPECT TO POTENTIALLY LETHAL VOLTAGES APPLY WHENEVER THE COVER IS REMOVED FROM THE MODEL 165. BEFORE PROCEEDING, THE USER MUST READ AND OBSERVE THE CAUTION NOTICE RELATING TO THE INSTALLATION OF THE DIGITAL STORAGE OPTION, LOCATED ON PAGE IV-17.

6.1 INTRODUCTION

Figure VI-1 is a block diagram of the Model 165. It shows all major circuit components, waveforms and voltage levels at critical points, signal paths, and logic-control paths. Additionally, a discussion of the diagram "walks" the reader through the circuit. The actual troubleshooting section therefore has been confined to a brief description of problems likely to be encountered. By checking voltages and waveforms at the indicated points, it should be possible for the user to narrow down a fault to one of the circuit boards—or even to the specific malfunctioning part. After localizing the problem, he should then communicate with the factory (or the factory-authorized representative in his area) for advice on the adjustment or repair. In the instance of a unit still under warranty, such communication before proceeding with a repair is particularly important; damage resulting from unauthorized work might not be covered by the warranty.

6.2 BLOCK DIAGRAM DISCUSSION

6.2A GENERAL RUN-THROUGH

The M165 has two distinct modes of operation: a Signal mode, and a Baseline-Subtraction mode. However, there is circuitry common to both modes. We will discuss first the flow of the input signal during the Signal mode of operation. Next we will take up signal flow during operation in the Baseline-Subtraction mode. Finally, trigger logic will be considered for both of the modes.

SIGNAL MODE

The signal to be processed is applied to the M165 at the Signal-Input connector. Depending upon the input function desired, the signal is then either ac- or dc-coupled to either a 10 kΩ or a 50 Ω input circuit. When the 10 kΩ impedance is selected, the signal passes through the High-Impedance Buffer before reaching the Sensitivity Attenuator. When the 50 Ω impedance is selected, the signal passes directly to this attenuator.

After the attenuator, the signal moves to the gain-of-five Wide-Band Amplifier—which is also the point at which the feedback resulting from boxcar processing is compared with the input. The output of the Wide-Band Amplifier is then sampled by the high-speed Sampling Gate. It also is monitored by the Overload Circuit, which determines whether the signal level is beyond the dynamic-range limitation of the Sampling Gate.

The Sampling Gate takes a sample of the input waveform. The sample is then "stretched" by the Sample and Hold (U1007). The duration of the sample is determined by either the Aperture-Duration pushbuttons on the M165 front panel, or by Aperture-Duration settings on the mainframe (M162).

After being stretched, the signal sample enters the Signal-Channel Integrator and a *second* sample (i.e., a sample of the stretched sample) is taken—this one by the low-leakage FET Q2001. This second sample is 1 μs in length for all aperture durations equal to or less than 1 μs, but it will track any aperture duration greater than 1 μs.

The Signal-Channel Integrator, in conjunction with Q2001, comprise the gated-integrator portion of the M165. It is here that noise reduction is accomplished. The output of the Signal-Channel Integrator (that is, the averaged signal) then goes to two places: one is the Feedback Amplifier; the other is the Output Amplifier.

The Feedback Amplifier (U1005) has a gain of 0.25 and its output is attenuated by a 50:1 resistive divider before it arrives at the inverting input of the Wide-Band Amplifier. Since the Wide-Band Amplifier is also a differential amplifier, it must establish a gain of 200 from its non-inverting input to the output of the Signal-Channel Integrator. Therefore, the output of the Signal-Channel Integrator will asymptotically approach 200 E_{IN}, where E_{IN} is the signal amplitude at the input to the Wide-Band Amplifier. The speed at which the Integrator output approaches 200 E_{IN} is governed by factors discussed in Subsection 4.2G of this manual.

The Output Amplifier (U1006), when in signal-mode operation, has its inverting input grounded by K1001. Since this too is a differential amplifier, its output in this mode represents the output of the Signal-Channel Integrator with respect to ground.

BASELINE-SUBTRACTION MODE

The block diagram shows that although the Signal-Channel path and the Baseline-Channel path are separate, the two channels also share a

common path. However, the common path is not utilized simultaneously by the two; they use it in alternation. How this multiplexing is performed will be explained later in the control-logic discussion.

It was stated earlier that the stretched signal sample from U1007 entered the Signal-Channel Integrator. What was ignored at that time is the fact that the stretched signal is also sent on the Baseline-Channel path—to low-leakage FET Q2009, etc. Thus the prior discussions of a second sample, noise reduction, and output to both the Feedback Amplifier and the Output Amplifier apply equally to the Baseline path.

When the M165 is in the Baseline-Subtraction mode, the contacts of relay K1001 are closed. Baseline information therefore passes through to the inverting input of the Output Amplifier. As a result, the baseline information now will be subtracted from the signal information.

6.2B TRIGGER CIRCUITS

The M165 relies on an input trigger from the M162 (at P1001-46) to initiate its sampling and gating functions. The relationship of these functions to the incoming trigger signals is shown in Figure VI-2, M165 Timing Diagram; the reader will find it helpful to refer to this diagram during the following discussion.

SIGNAL-MODE LOGIC

The incoming trigger signal is amplified and inverted (Q1021, 1022), and then NORed with a logic "1" at U1011. Thus U1011 has the effect of inverting the trigger once again. Next, the trigger is stretched to 100 ns (U1011), then ORed with the BL Gate TRIG (which is "low"). At U1012, the trigger either is blocked or is allowed to pass—depending upon the Channel Sync input. For the present, we will assume that Channel Sync is inactive; however, it is important to note that the channel-sync line to U1012 defaults "high" regardless of the Channel-Sync switch position ("1" or "0") when no input is applied to this connector.

The trigger is then steered, either to the Nanosecond-Gate Generator or to the A-T Gate Generator, by the Gate-Generator Trigger Steer line as follows: when any Aperture-Duration pushbutton on the M165 is depressed, the trigger will be steered to the Nanosecond-Gate Generator. If no such pushbutton is depressed, the trigger is steered to the A-T Gate Generator. Thus one of the two Gate Generators receives the trigger signal and then issues a gating pulse to the Sampling Gate. The duration of the gating pulse, of course, is determined either by the Aperture-Duration pushbuttons on the M165, or by the AD settings on the M162. In the latter case, should the selected AD overlap the end of the DRF, an Overlap Signal is sent back to the mainframe.

We return to the Sampling Gate. As described earlier, the sample taken from the input signal by the Sampling Gate is stretched by the Sample and Hold. Now let us consider how the Integrator-Switch Logic "gets the word" that this stretched signal is to be sampled by the Signal-Channel Integrator.

When the Nanosecond-Gate Generator is enabled, the trigger to that generator is also sent to U1010, where it is ORed with a "low", because the A-T Gate Generator is inactive. The trigger is then lengthened to 1 μs, inverted by U1009, and applied to two NOR gates (both labeled U1008). The lower U1008 on the block diagram has one input "high" due to the BL SW Logic section of the Baseline/Signal-Channel Alternator. This lower part of U1008 is inhibited and does not allow the 1 μs pulse to activate the Baseline-Channel-Integrator FET—Q2009. On the other hand, the "low" applied to the *upper* U1008 allows the 1 μs pulse to activate the Signal Integrator Switch Drivers.

When the A-T Gate Generator is enabled, the Integrator-Switch Logic "gets the word" in a somewhat different fashion. Recall that when the Nanosecond-Gate Generator was enabled, U1010 received the trigger from the Nanosecond-Gate-Generator-Trigger line. But this line is inactive ("low") when the A-T Gate Generator is enabled. U1010 now receives its trigger from a buffered (Q1009) replica of the actual gate pulse. This replica is ORed with the 1 μs pulse (from the 1 μs monostable) at U1009. Therefore, the output of U1009 will be a pulse that is one microsecond or longer—depending upon the Aperture Duration that has been selected.

The Signal-Integrator Switch Driver converts the TTL-level, one-microsecond-or-longer pulse to the level necessary to cause FET Q2001 to turn on. Thus, a second sample of the input signal is taken.

(Note that the Gate-Generator Trigger Steer line is fed also to the Trigger Hold-off block. The function of this circuitry is to prevent the mainframe from supplying trigger signals at a rate faster than 10 kHz when the Nanosecond-Gate Generator is operative.)

The final point to consider in Signal-Mode Trigger Logic is that the Signal-Switch logic section of the Baseline/Signal-Channel Alternator is holding "low" the line to the Signal-Feedback-Switch Driver. So the last-mentioned is holding Q1005 (the Signal-Feedback Switch) "off", or open-circuited. As a result, signal information is not shunted to ground by Q1005, but is allowed to pass on to the Feedback circuit.

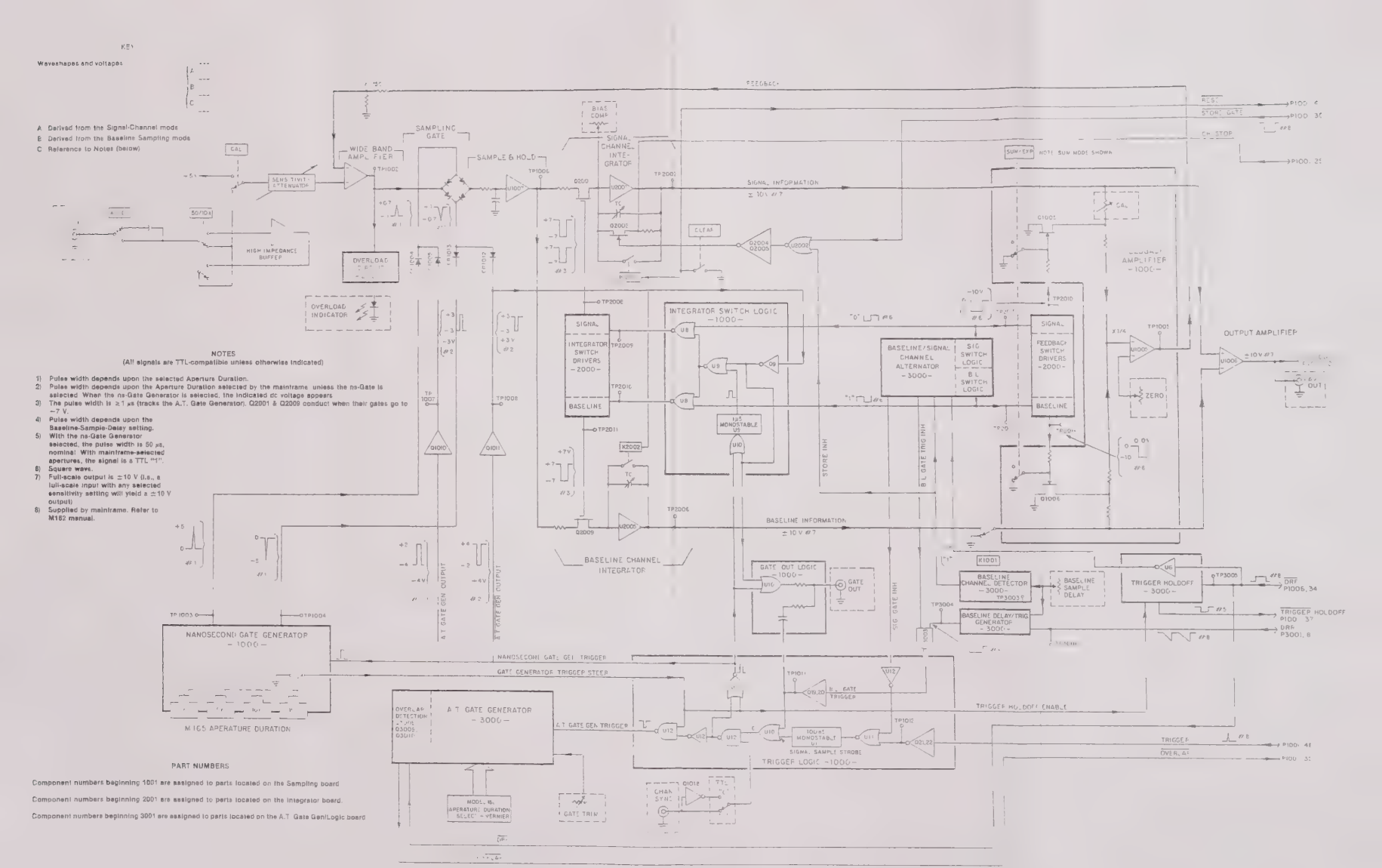

KEY
Waveshapes and voltages
A Derived from the Signal-Channel mode
B Derived from the Baseline Sampling mode
C Reference to Notes (below)
NOTES
(All signals are TTL-compatible unless otherwise indicated)
1) Pulse width depends upon the selected Aperture Duration.
2) Pulse width depends upon the Aperture Duration selected by the mainframe unless the ns-Gate is selected. When the ns-Gate Generator is selected, the indicated dc voltage appears.
3) The pulse width is ≥1 µs (tracks the A.T. Gate Generator). Q2001 & Q2009 conduct when their gates go to −7 V.
4) Pulse width depends upon the Baseline-Sample-Delay setting.
5) With the ns-Gate Generator selected, the pulse width is 50 µs, nominal. With mainframe-selected apertures, the signal is a TTL "1".
6) Square wave.
7) Full-scale output is ±10 V (i.e., a full-scale input with any selected sensitivity setting will yield a ±10 V output).
8) Supplied by mainframe. Refer to M162 manual.
PART NUMBERS
Component numbers beginning 1001 are assigned to parts located on the Sampling board
Component numbers beginning 2001 are assigned to parts located on the Integrator board.
Component numbers beginning 3001 are assigned to parts located on the A.T. Gate Gen/Logic board
FEEDBACK
BIAS COMP
SAMPLING GATE
WIDE BAND AMPLIFIER
SAMPLE & HOLD
SIGNAL CHANNEL INTEGRATOR
SIGNAL INFORMATION
CAL
SENSITIVITY ATTENUATOR
50/10k
HIGH IMPEDANCE BUFFER
OVERLOAD DETECTOR
OVERLOAD INDICATOR
CLEAR
INTEGRATOR SWITCH LOGIC −1000−
SIGNAL INTEGRATOR SWITCH DRIVERS −2000−
BASELINE
BASELINE/SIGNAL CHANNEL ALTERNATOR −3000−
SIG SWITCH LOGIC
B.L. SWITCH LOGIC
SIGNAL FEEDBACK SWITCH DRIVERS −2000−
BASELINE
AMPLIFIER −1000−
OUTPUT AMPLIFIER
ZERO
OUT
STORE INH
B.L. GATE TRIG INH
SIG GATE INH
BASELINE INFORMATION
BASELINE CHANNEL INTEGRATOR
GATE OUT LOGIC −1000−
GATE OUT
BASELINE CHANNEL DETECTOR −3000−
BASELINE SAMPLE DELAY
TRIGGER HOLDOFF −3000−
BASELINE DELAY/TRIG GENERATOR −3000−
TRIGGER HOLDOFF
NANOSECOND GATE GENERATOR −1000−
M165 APERATURE DURATION
A.T. GATE GEN OUTPUT
NANOSECOND GATE GEN TRIGGER
GATE GENERATOR TRIGGER STEER
A.T. GATE GENERATOR −3000−
A.T. GATE GEN TRIGGER
B.L. GATE TRIGGER
TRIGGER HOLDOFF ENABLE
10ns MONOSTABLE
SIGNAL SAMPLE STROBE
TRIGGER LOGIC −1000−
MODEL 165 APERATURE DURATION SELECT − VERNIER
A.T. GATE TRIM
CHAN SYNC
TTL
TRIGGER
OVERLAP

Figure VI-1. BLOCK DIAGRAM

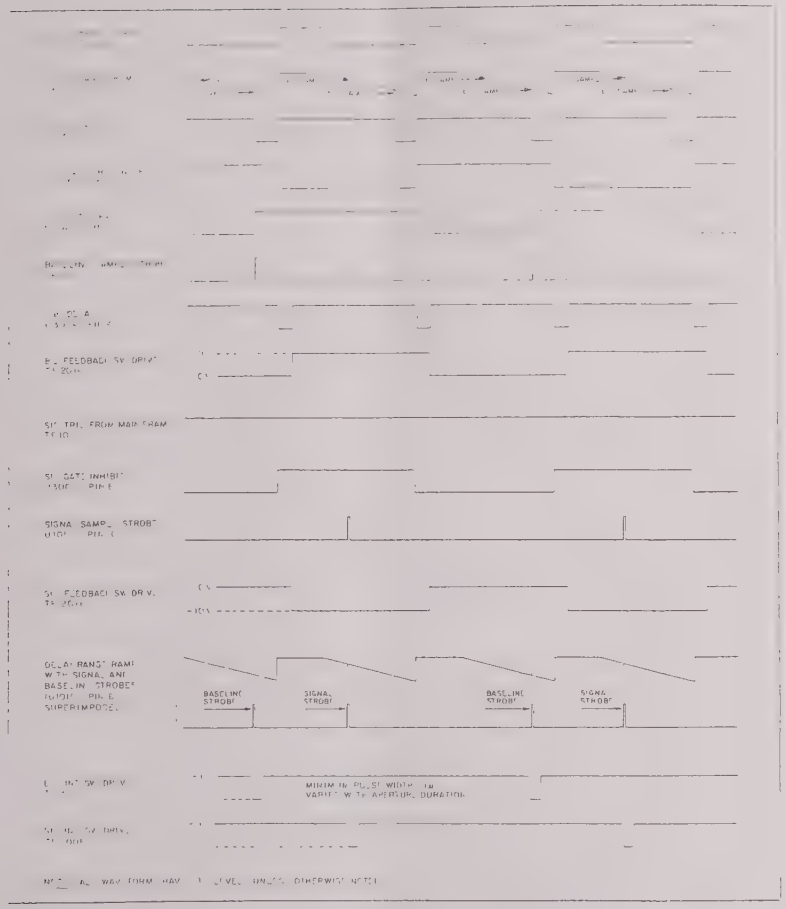


Figure V-2. MODEL 161 TIMING

BASELINE-SUBTRACTION TRIGGER LOGIC

In our discussion of trigger logic when in the Baseline mode, we will examine first the initiation of the mode, then the derivation of its timing, and finally the trigger-logic paths.

To select this mode, the Baseline-Sample-Delay control is rotated from its fully CCW "off" position. The Baseline-Channel Detector compares the voltage on the wiper of the "pot" against a preset level, and determines whether the Baseline mode is to be enabled. If the answer is "yes", the output of the Baseline-Channel Detector goes high. The output of this detector controls the Baseline/Signal-Channel Alternator, and a "high" output tells the Alternator to begin alternating. Conversely, a "low" on the output line stops the alternating—and stops it so that the Alternator remains in the Signal-Channel mode.

The Baseline Delay/Trigger Generator (BD/TG) generates the Baseline trigger by comparing the voltage level at the wiper of the same "pot", mentioned above, with the Delay-Range Ramp. (This Delay-Range Ramp is generated by the mainframe and enters the M165 at P3001-8.) The active output of the BD/TG (TP3004) is a "low" pulse, the width of which is dependent upon the setting of the "pot". U3003 allows this pulse to pass to the Trigger-Logic section—but only when its *other* input is high. This other input—called the Baseline-Gate Trigger Inhibit line—comes from the Baseline/Signal-Channel Alternator. We will therefore digress from the discussion of trigger logic to consider the action of this Alternator.

The Baseline/Signal-Channel Alternator can be viewed as a sophisticated flip-flop: it must receive a "trigger" from the Baseline-Channel Detector in order to alternate. As a result of the alternation, the output at either the Signal-Switch Logic or the BL Switch Logic is at half the frequency of the Delay-Range Frame signal (DRF) coming from the mainframe via P1001-34. (Refer to the M162 manual for a discussion of the relationship between the DRF and the main trigger that appears at P1001-46.) So when the Alternator is enabled by the Baseline-Channel Detector, it puts out: (a) signals that enable alternately the Signal-gate Inh and the BL-Gate Inh lines; and (b) signals that enable alternately the Signal-Switch Logic and BL-Switch Logic lines. All four of these signals are square waves at one-half the DRF frequency.

We return now to our discussion of trigger logic during Baseline Sampling, and consider the relationship of the Signal-Gate Inh, the BL-Gate Inh and the main trigger.

As usual, the main trigger signal enters at P1001-46. However, at U1011 the Signal-Gate Inh input can allow the trigger to pass, or block it. (Notice on the Timing Diagram that when Signal-Gate Inh is low, the trigger is blocked at U1011.) However, when Signal-Gate Inh is low, BL-Gate Inh is high, thereby allowing a BL-Trigger pulse to pass through U3003 and enter the Trigger-Logic circuit. The pulse will arrive at U1010 and initiate a gate-generator trigger exactly as if it were a main-trigger signal discussed earlier in the Signal mode. As opposed to operation in the Signal mode, however, now the Signal-Switch Logic and the BL-Switch Logic are at "1" and "0" respectively. Therefore, the lower U1008 in the Integrator-Switch Logic section issues a pulse that tells the Baseline-Integrator Switch Driver to allow a *Baseline* sample to be taken, at Q2009, for the Baseline-Channel Integrator. Conversely, the upper U1008 is inhibited, and no pulse is issued to the Signal-Integrator Switch Driver.

In addition, the Baseline-Feedback Switch Driver holds "off" the Baseline Feedback switch (Q1006), allowing Baseline information to enter the feedback loop. Conversely, the Signal-Feedback switch (Q1005) is "on", shunting Signal information to ground and preventing it from entering the feedback loop at this time.

When the *next* DRF signal arrives at P1006-34, the Baseline/Signal Channel Alternator changes state. Signal-Switch Logic goes to "0" and BL-Switch Logic goes to "1". Additionally, the BL-Gate Trigger Inh goes low to prevent a BL-Gate Trigger signal from entering the trigger-logic section; the Signal-Gate Inh line goes high to allow a main trigger to enter the trigger-logic section. A signal sample thus will be taken as described earlier in the Signal-mode operation.

Summing up this section of the discussion, it will be noted that the main trigger (from the M162) always initiates the Signal-Sample sequence; the DRF signal from the M162, by means of the Baseline Delay/Gate Generator, is responsible for the Baseline-Sample sequence. The Baseline/Signal-Channel Alternator is the "command" section for the Baseline-Subtraction mode. By virtue of its alternations, it allows the correct trigger to be chosen and thus the correct sample to be taken. It also governs selection of the Feedback Switches so that the appropriate information can enter the feedback loop back to the Wideband Amplifier.

6.2C SUMMATION MODE

In the preceding discussion, it was pointed out that the Feedback information caused the output of the Signal-Channel Integrator to approach 200 $E_{/\!/}$ asymptotically. By implication, of course, the same asymptotic increase applies to the level of the Baseline-Channel Integrator when the Baseline-Sampling mode is operative. When the Summation mode is chosen, however, there is no feedback in either the Signal or the Baseline paths. As shown on the block diagram, the gates of both Q1005 and Q1006 are shorted to ground when the

EXP/SUM pushbutton is released. Both FETs thus short to ground any information before it can enter the feedback amplifier. The Signal circuits and Baseline circuits then function as normal integrators: a given amount of input causes a specific rate of change at the output. The rate of change is affected by the duty factor and the selected Time Constants for any given input level. In other words, the output now does not asymptotically approach 200 E_{IN}, but rather rises linearly until the limits are reached or the input signal changes.

6.2D STORE INH

When the Digital Storage Option (DSO) is functioning, the STORE GATE input at P1001-30 changes from its normal "high" (DSO *not* functioning) to a TTL "low". Now when the output of the Baseline-Channel Detector goes low, because baseline sampling has been selected, its signal is NORed with the input at P1001-30 to produce a low output from U2002. This "low" is inverted and amplified by Q2009, and turns off Q2002. When the latter is off, the D/A output of the DSO is disconnected from the summing point of the Gated Integrator, U2001. The result is that, during the baseline-sampling sequence, digital storage is prevented from affecting the Signal-Channel Integration. Explanation: The DSO takes its input signal from the output of the M165. After performing an A/D conversion, storing the digital data, then reconverting the data to analog form, the DSO feeds out a signal that is a steady replica of the original output of the M165. This steady signal is then injected into the Signal-Channel Integrator. The S-C Integrator thus is held at a relatively fixed level until it takes its next sample—a procedure that tends to counteract "droop" in the stored level of the signal sample. Obviously, if Baseline Sampling is in progress, the output signal should *not* be fed back to the S-C Integrator because it now does not represent the signal sample, but rather the signal sample *minus* the baseline sample. Refer to the M162 manual, Subsection 6.2E, for a description of the relationship of the DSO to signal processing.

6.3 TROUBLESHOOTING PROCEDURE

WARNING!

PRECAUTIONS WITH RESPECT TO POTENTIALLY LETHAL VOLTAGES APPLY WHENEVER THE COVER IS REMOVED FROM THE MODEL 165. BEFORE PROCEEDING, THE USER MUST READ AND OBSERVE THE CAUTION NOTICE RELATING TO THE INSTALLATION OF THE DIGITAL STORAGE OPTION, LOCATED ON PAGE IV-17.

6.3A INTRODUCTION

Assuming that the reader now understands the circuits of both the M162 and M165, and assuming also that he is familiar with the process-of-elimination technique as applied to both analog and pulse-type circuitry, he may now proceed to the following troubleshooting diagnosis. Should the findings along the way correspond exactly with those indicated here, the user will be enabled directly to localize circuit problems to the specific board—or even the component—at fault. On the other hand, the diagnosis procedure is quite obviously not an all-inclusive resumé of possible malfunctioning. Rather it is a combination of information and hints intended to steer the reader along investigative paths.

6.3B EQUIPMENT REQUIRED

(1) Oscilloscope. See Subsection 5.2(2). Additionally, for troubleshooting the nanosecond gate generator circuits, a sampling scope or a 1 GHz realtime scope will be required.

(2) Digital Voltmeter. See Subsection 5.2(3).

6.3C PRELIMINARY STEPS

To prepare the instrument it must be opened, placed on extender cables, and warmed. Refer in this manual to Subsections 5.2(1) and 5.3(1-4).

6.3D POWER-SUPPLY CHECKS

The ESSENTIAL first step is to establish that all power-supply voltages are correct.

Measure	At	Supplied By
+ 5 V	Pin 14 of any 14-pin IC on Sampling Board*	U3005
+ 50 V	P1001-38	M162
– 50 V	P1001-39	M162
+ 15 V	P1001-26,28	M162
– 15 V	P1001-22,24	M162

***NOTE:** If + 5 V is not present at any pin 14 on the Sampling Board, check, P1001-18,20 for voltage between + 7 and + 11 volts. This unregulated voltage is supplied by the M162.

6.3E ISOLATION OF FAULTS

The essence of fault isolation is to localize the malfunction to a specific mode of operation—or to a specific feature of a mode of operation. (If the fault is common to more than one mode—or to more than one feature of a mode—that knowledge too narrows down the search.) Once the problem has been confined to a specific circuit of a board, the key waveforms and voltages given in Figure VI-1 should help to pin-point a specific component.

Begin by presetting both the M162 and M165 as described in Initial Checks, Subsection 3.4A(1-2).

(1) The fault is the same whether the M165 is in the A or B channel of the M162.

NO: Check the M162.

YES: Continue.

(2) Does the fault occur only during Signal-Mode operation? Only during Baseline-Sampling operation? In both operations?

(a) Only during Signal Mode (Baseline Sampling off)

The typical failure will result in the output meter being pegged at full scale. Move the two two-pin plugs at the Sampling Gate to their Test positions and place a jumper across the exposed pins. See Figure VI-3. Observe the panel meter. If it changes to some level other than a pegged condition, vary the ZERO control to see if the meter follows the changes of the control. You should note a swing of the meter similar to that expected when the unit is functioning normally.

METER DOES NOT TRACK ZERO CONTROL: Move to (2)(a)(ii).

METER TRACKS ZERO CONTROL: Continue.

(i) Use the scope at TP1007 and TP1008 to check for a 5 μs pulse similar to that shown in the Block Diagram. If it is not as indicated, backtrack to the A.T. Gate Gen. Trigger. The (nominally) 100 μs pulse should be observed. If not, troubleshoot the Trigger Logic section, beginning where the Trigger enters the plug-in at P1001-46.

(ii) If you're at this point it means that either the panel meter did *not* track the ZERO control, or the A.T. Gate Generator *did* perform satisfactorily. Leave the Sampling Gate jumpered as described above. Put the scope on TP2008 and look for the 5 μs pulse as shown on the Block Diagram.

PULSE IS NOT THERE: Backtrack to TP2009. A 5 μs pulse should be seen. Assuming that there is a 5 μs pulse at TP2009, trace it through the Integrator-Switch Logic section to find out what happened to it before it reached TP2008.

PULSE IS THERE: Continue.

(iii) Measure the voltage at TP2016; it should be – 10 V.

NO: Trouble in the Feedback-Switch Drivers. Check the circuit diagram and trace the missing – 10 V.

YES: Continue.

(iv) Interchange U2001 and U2005, the two Integrator IC's. Is the panel meter now unpegged and able to track the ZERO control?

YES: Return the connections on the Sampling Gate to Normal (Figure VI-3). The module should now work normally (Signal-Mode), and you need a new U2001 to replace the one taken from the Baseline Mode.

NO: Continue.

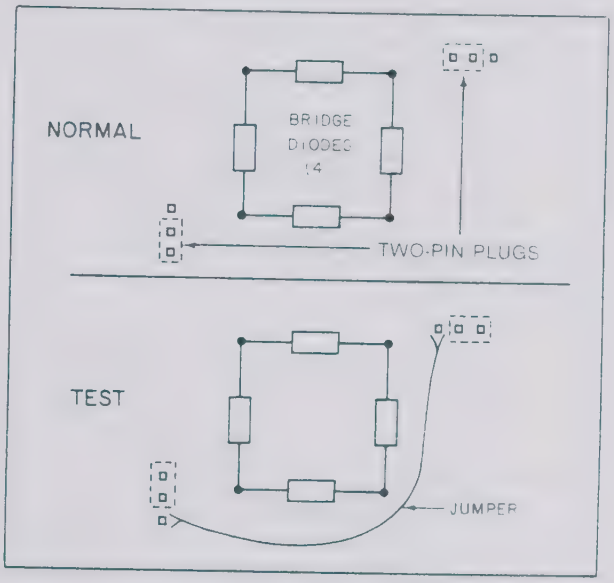


Figure VI-3. SAMPLING GATE TEST SET-UP (SAMPLING BOARD)

(v) Return the two IC's to their previous locations; the module was calibrated for them that way. Now interchange U1006 and U1005 (pin-for-pin compatible). Measure the voltage at TP2002. It should be around zero volts and should track the ZERO control—but in the opposite direction.

YES: Feedback Amplifier (U1005) is bad; replace it. Restore the Sampling Gate connections to Normal.

NO: The trouble is not in the Feedback Amplifier, so return U1005 and U1006 to their former positions. Continue.

(vi) Break the Feedback loop by pulling J24 from the Sampling board. Disregard any peculiar movements of the panel meter. Move the Sensitivity control to the

5 V position, then depress the CAL pushbutton. Now measure the voltage at TP1002; it should be approximately + 250 mV.

NO: Trouble in the Wideband Amplifier. Call the factory for help.

YES: Now measure the voltage at TP1006; it should be + 500 mV.

NO: U1007 is bad. Replace it, return the Sampling-Gate connections to Normal, and reconnect J24

YES: Your search was unsuccessful. Communicate with the factory.

(b) The fault occurs only during Baseline Sampling

Put the scope on TP3005 and check for the presence of the DRF signal.

NO: Trouble in the M162.

YES: Continue.

(i) Turn the control for the Baseline-Sample Delay on and off repeatedly while listening attentively. You should hear the faint sound of a reed relay clicking.

NO: Measure the voltage at TP3003 when the Baseline-Sample Delay is turned off; it should be zero volts. When the control is turned on, the voltage should measure approximately + 12 V. If these conditions seem to be correct, then suspect either Q3011 or relay K1001.

YES: Continue.

(ii) Connect the scope to TP3006. The DRR signal there should correspond with its description in the M162 manual.

NO: Check the M162.

YES: Continue.

(iii) Turn the Baseline-Sample Delay control to midrange. Put the scope on TP3004. A pulse such as is shown on the Block Diagram should appear, and its width should vary with the setting of the Baseline control.

NO: Trouble in the Baseline Delay/Trigger Generator.

YES: Continue.

(iv) Verify the timing of the Baseline/Signal-Channel Alternator by comparing the outputs of the Sig Sw Logic, BL Sw Logic, BL Gate Trig Inh, and the Sig Gate Inh with the signal timing given in the Timing Diagram, Figure VI-2. **NOTE:** Sig Sw Logic is not on the Timing Diagram; it is the same as BL Trig Inh, but is delayed by 2 μs. BL Sw Logic is not the Timing Diagram either; it is the same as Sig Gate Inh, but is delayed by 2 μs.

If proper timing signals are not displayed at the output of the Alternator or at any of the above-mentioned logic paths, check for malfunctioning in those circuits. If the Alternator's signals appear to be doing their job, continue.

(v) Trace the Baseline-Gate Trigger signal through the Trigger-Logic path. If it is not going through, then find out where it is being lost. If it is going through, then check TP2011 for the 5 μs pulse shown on the Block Diagram.

NO: Move to TP2010. Another 5 μs pulse should be seen there. If it is, there is trouble in the Integrator Switch Drivers. If it isn't, trace back through the Integrator-Switch logic section.

YES: Continue.

(vi) Check that the waveform at TP2014 is as shown on the Block Diagram.

NO: Move the scope to TP2013 to double-check. The Block-Diagram waveshape should be present, since earlier we had declared that the Baseline/Signal-Channel Alternator was functioning properly. Suspect U2005 or the contacts of relay K1001. Do not interchange U2005 and U2001 in this instance; if possible, substitute a new U2005.

YES: Your search was unsuccessful. Communicate with the factory.

(c) The fault is common to both the Signal Mode and the Baseline-Sampling Mode. Reminder: Have you checked the power-supply voltages? Have you tried the module in the other bin position?

Although this type of malfunction assumes a problem in the circuits common to both modes, the easiest way to attack it is to first perform the procedure given above for the Signal Mode. If the problem

is not solved, then continue with the procedure outlined for checking the Baseline-Sampling Mode. If the fault still has not been localized, communicate with the factory.

(3) The fault is evident when using one aperture gate generator, but not when using the other.

There are two Aperture Gate Generators in the M165. The Nanosecond-Gate Generator controls the 2 ns, 5 ns, 10 ns, and 15 ns apertures. The A.T. Gate Generator controls apertures from about 20 ns to 5 ms. Therefore, if there is a problem when using one, and not when using the other, the problem very well may be confined to the generator.

Unfortunately, the situation is not that clear-cut. Problems occurring only when the Nanosecond-Gate Generator is in use might be due to the Generator itself—or might be caused by the Sampling Gate. Although the diode bridge may seem to be perfectly fine when the A.T. Gate Generator is in use, there could be a fault in the bridge that would prevent it from operating properly with the extremely short gates provided by the Nanosecond-Gate Generator. Moreover, if the problem indeed is in the Nanosecond-Gate Generator, the user should go no further: this section of the M165 is definitely *not* serviceable in the field.

(a) The fault occurs only when using the Nanosecond-Gate Generator. Use a sampling scope or a 1 GHz realtime scope at TP1003 and TP1004 to verify that the pulses indicated on the Block Diagram are present.

YES: See if the pulses arrive at the diode bridge with the wave shapes and amplitudes noted on the Block Diagram. If they do not, backtrack through CR1004 and CR1005. If the pulses are arriving satisfactorily at the bridge, then the trouble is in the bridge circuitry.

NO: Verify that the Generator is receiving the (nominally) 100 ns pulse from the Trigger Logic Section. If it is not, then troubleshoot the latter. If it is receiving proper input pulses, go no further. Communicate with the factory.

(b) The fault occurs only when using the A.T. Gate Generator. Again, check that the output pulses shown on the Block Diagram are emerging from the Gate Generator. If they are, the trouble must lie between the Generator and the diode bridge. (The bridge must be good, because it functions properly when the Nanosecond-Gate Generator is in use.)

If proper output pulses are not observed, make sure—as before—that the approximately 100 ns pulse input for the Generator is being supplied by the Trigger-Logic section. If it is proved that the A.T. Gate Generator is receiving the proper input, but not providing the proper output, then the following procedure should help to isolate the problem within the Generator.

Set the M162 as follows:

Aperture Delay
% Initial Delay A: 50%
% Initial Delay B: 50%
Range: 20 μs
Trigger Mode: EXT
Scan pushbuttons: EXT and A depressed; all others released
Aperture Duration: 5 μs, and CAL
Scan Time: 1 s, and CAL
Function: A (Digital Storage OFF)
Mainframe Time Constant: 0.1 ms, and CAL

Set the M165 as follows:

Time Constant: 1 μs
Pushbuttons: EXP, GND, and DC depressed; all others released

(i) Connect a 10 kHz trigger source to the mainframe Trigger Input; adjust the Trigger Level control for proper triggering as indicated by the Triggered lamp.

(ii) Monitor the signal at TP3001. One should see a negative-going transient at 10 kHz. The "peak" will be at about −9 V and the baseline at nominally −6 V. The width will be only a few nanoseconds.

(iii) Monitor the signal at the collector of Q3002. The signal should be a 5 μs pulse switching between −4 V and +2 V, approximately. The complement of that signal should be present at the collector of Q3004. These are the signals which (eventually) drive the diode-bridge gate. If their durations are incorrect, see if they can be adjusted to 5 μs (by means of the M165's front-panel Gate Trim adjustment) before concluding that the circuit is malfunctioning.

(iv) Rotate the Aperture Duration switch (M162) through its entire range. (It will be necessary to reduce the trigger rate as

longer AD's are selected.) For each position, the observed pulse width (at the collector of either Q3002 or Q3004) should correspond to the Aperture Duration selected. In the SPEC position—assuming that no "special" capacitor has been installed—the pulse width should be somewhere between 5 ns and 50 ns, though there well might not be any pulse at all.

If problems are noted with any particular setting of the AD switch, note that the latter controls relays K3001 through K3007, and that these relays do the actual switching of timing capacitors for the different switch settings. Relay K3005 is energized also when any one of the following apertures are chosen: SPEC, 500 μs, 50 μs, or 5 μs.

(v) Return the AD setting to 5 μs. Now vary the inner knob of the AD control. The pulse width should vary linearly from its calibated value of 5 μs to a maximum of (nominally) 50 μs when the multiplier knob is fully clockwise.

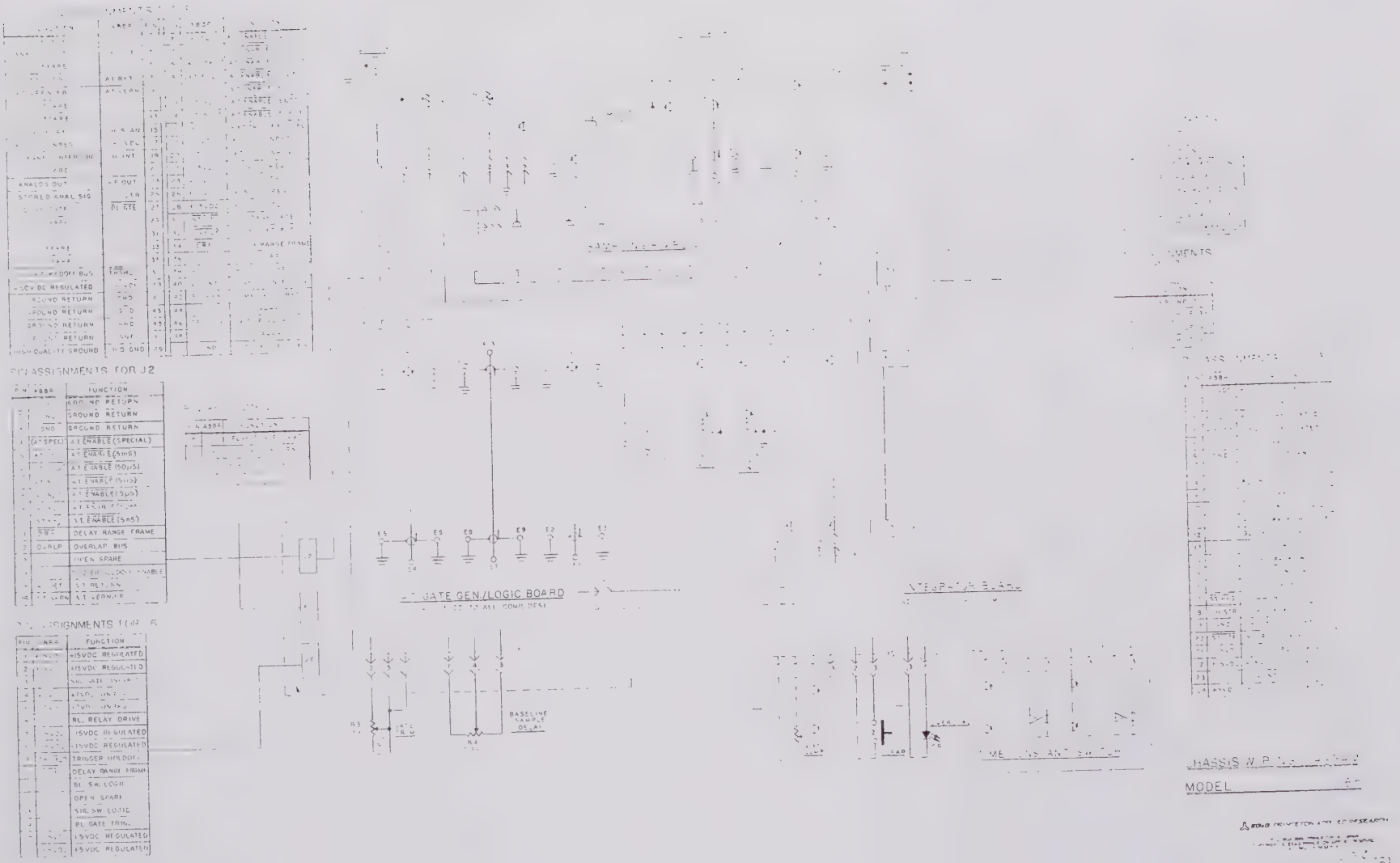
(vi) To check Overlap detection, note that the circuitry consists primarily of two of the gates of U3001 and the amplifier Q3009/Q3010. These gates monitor both the gate pulse and the DRF complement. The gates are arranged so that any time there is a gate pulse in progress, but no DRF, Q3008 activates the Overlap-Light Drive circuit in the mainframe.

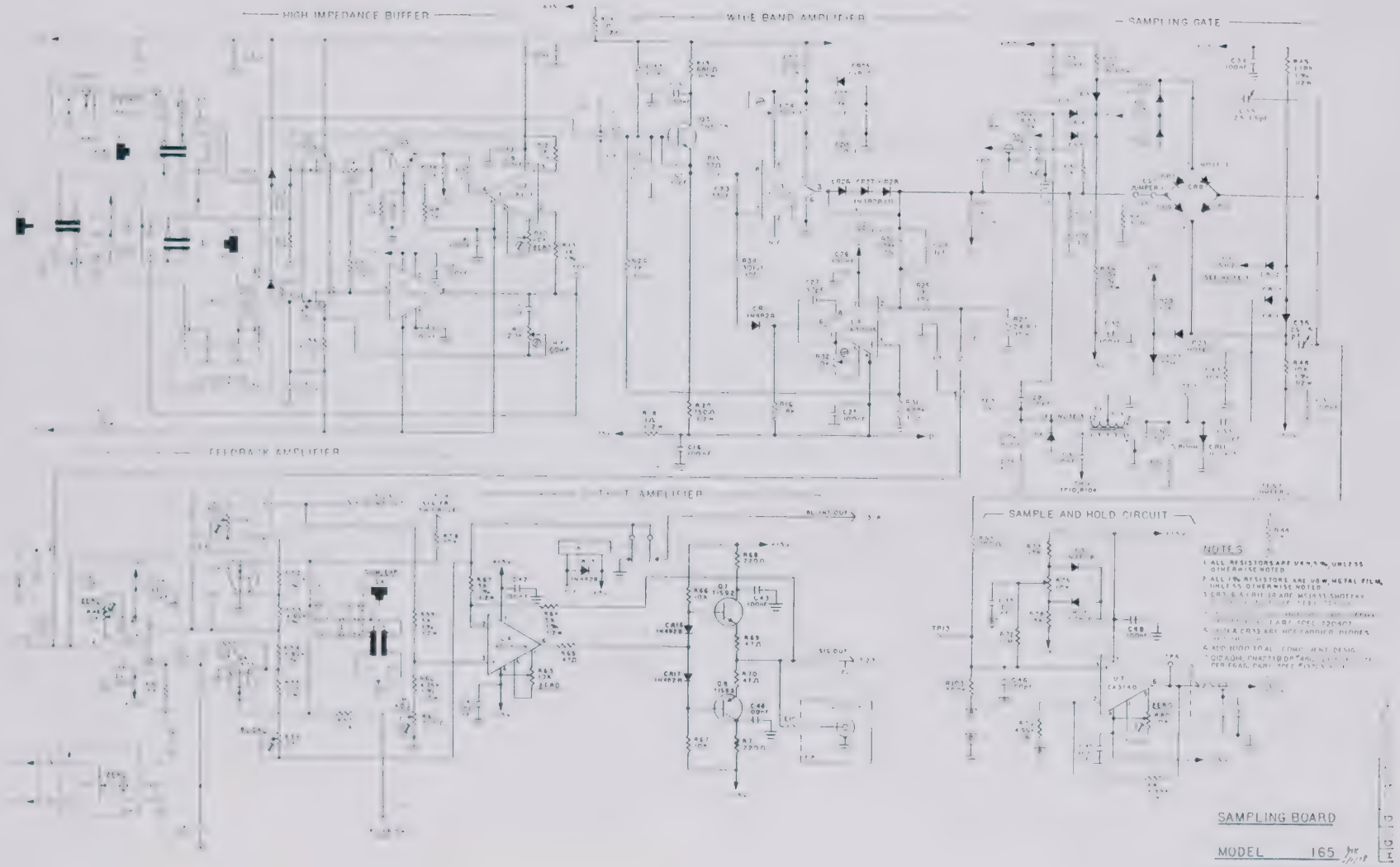
(vii) If these words are beginning to blur, and you still have not located the fault in the A.T. Generator, communicate with the factory.

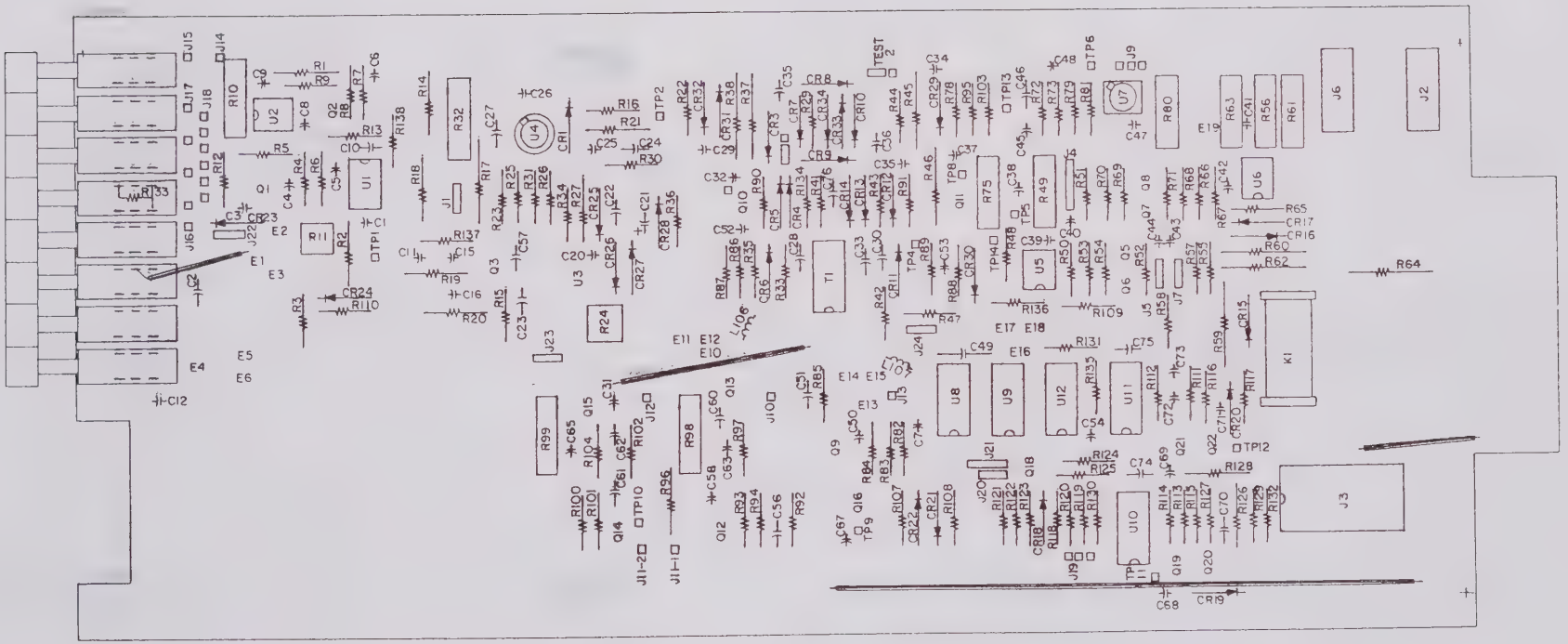
SECTION VII
SCHEMATICS

Page

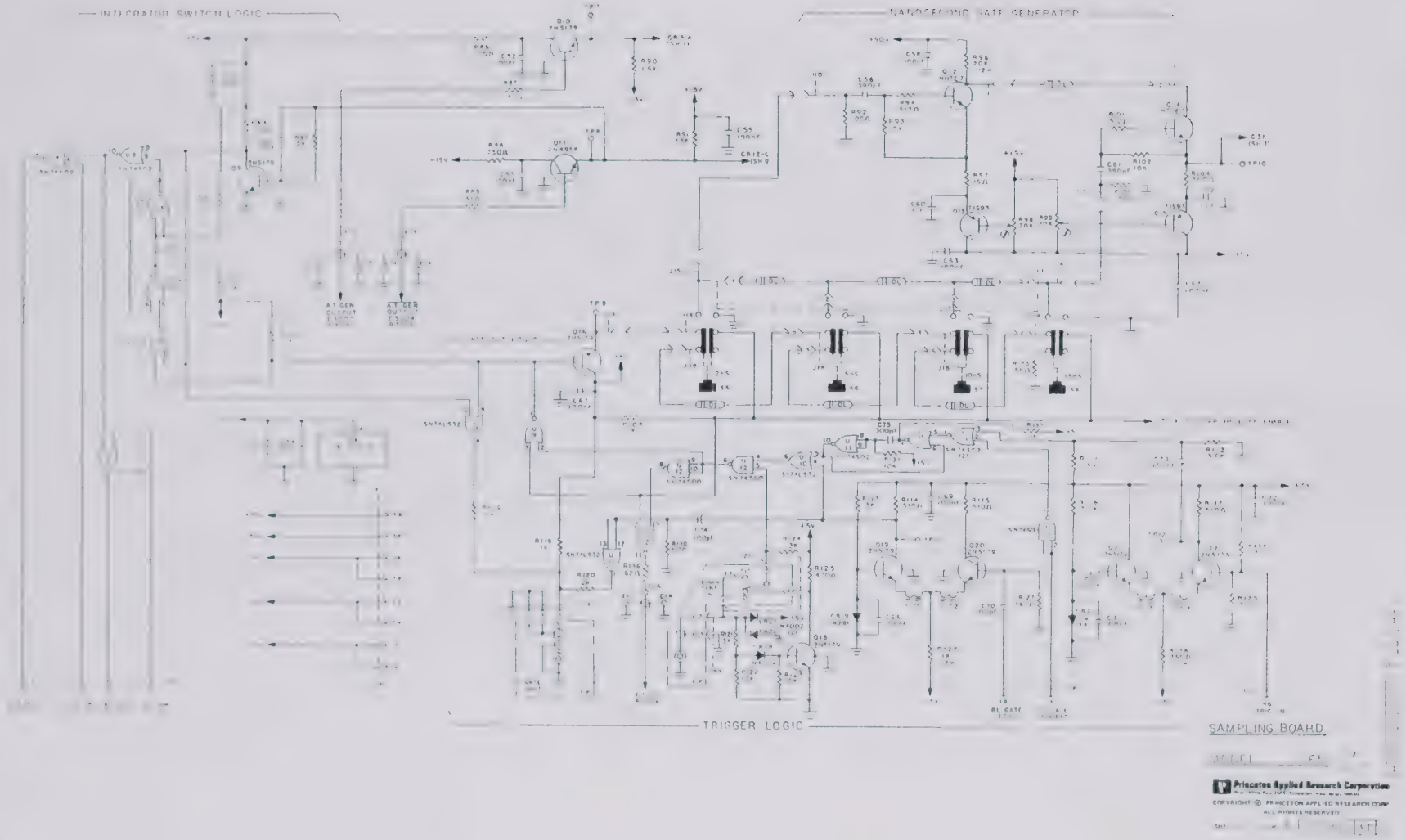
Table of Contents VII-1
Chassis Wiring Diagram (12500-D-SD) VII-2
Sampling Board Schematic Diagram (12050-D-SD; 1 of 2) VII-3
Sampling Board Parts Location Diagram VII-4
Sampling Board Schematic Diagram (12050-D-SD; 2 of 2) VII-5
Integrator Board Parts Location Diagram VII-6
Integrator Board Schematic Diagram (11976-D-SD) VII-7
A.T. Gate Generator/Logic Board Schematic Diagram (11948-D-SD; 1 of 2) VII-8
A.T. Gate Generator/Logic Board Schematic Diagram (11948-D-SD; 2 of 2) VII-9
A.T. Gate Generator/Logic Board Parts Location Diagram VII-10

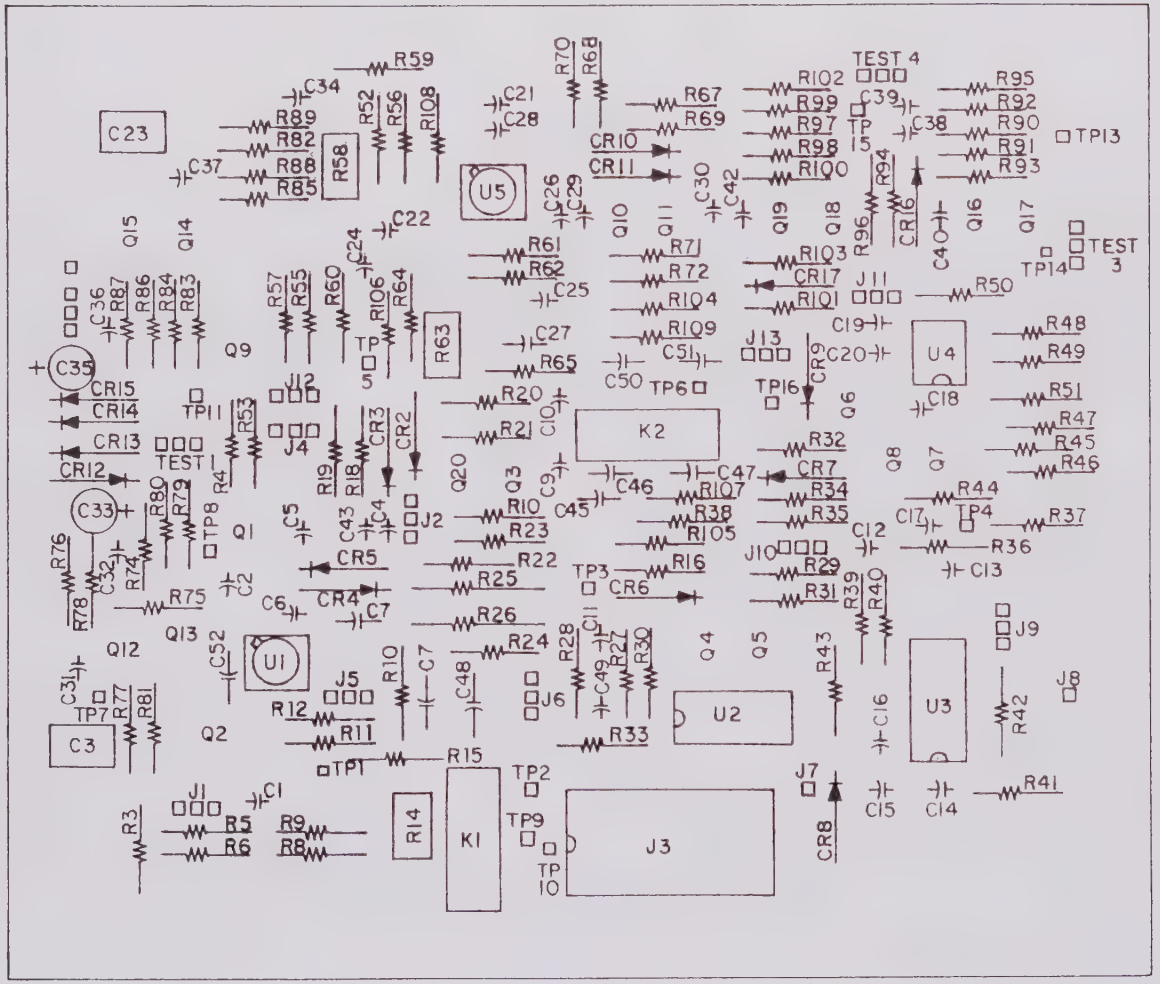

ANALOG OUT
+5VDC REGULATED
GROUND RETURN
DIGITAL GROUND RETURN
HIGH QUALITY GROUND
PIN ASSIGNMENTS FOR J2
PIN ABBR
FUNCTION
GND NO RETURN
GROUND RETURN
SND
GROUND RETURN
(A-SPEC)
A1 ENABLE (SPECIAL)
A1 ENABLE (5MS)
A1 ENABLE (50US)
A1 ENABLE (5US)
A1 ENABLE (5MS)
DELAY RANGE FRAME
OVRLP
OVERLAP BUS
OPEN SPARE
A1 RELAY
A1 RELAY
PIN ASSIGNMENTS FOR J3
PIN ABBR
FUNCTION
+15VDC REGULATED
+15VDC REGULATED
RL RELAY DRIVE
-15VDC REGULATED
+15VDC REGULATED
TRIGGER HOLDOFF
DELAY RANGE FRAME
BL SW LOGIC
OPEN SPARE
SIG SW LOGIC
BL GATE TRIG
-15VDC REGULATED
+5VDC REGULATED
GATE GEN./LOGIC BOARD
BASELINE SAMPLE DELAY
MODEL


HIGH IMPEDANCE BUFFER
WIDE BAND AMPLIFIER
SAMPLING GATE
FEEDBACK AMPLIFIER
T-H AMPLIFIER
SAMPLE AND HOLD CIRCUIT
NOTES
SAMPLING BOARD
MODEL 165



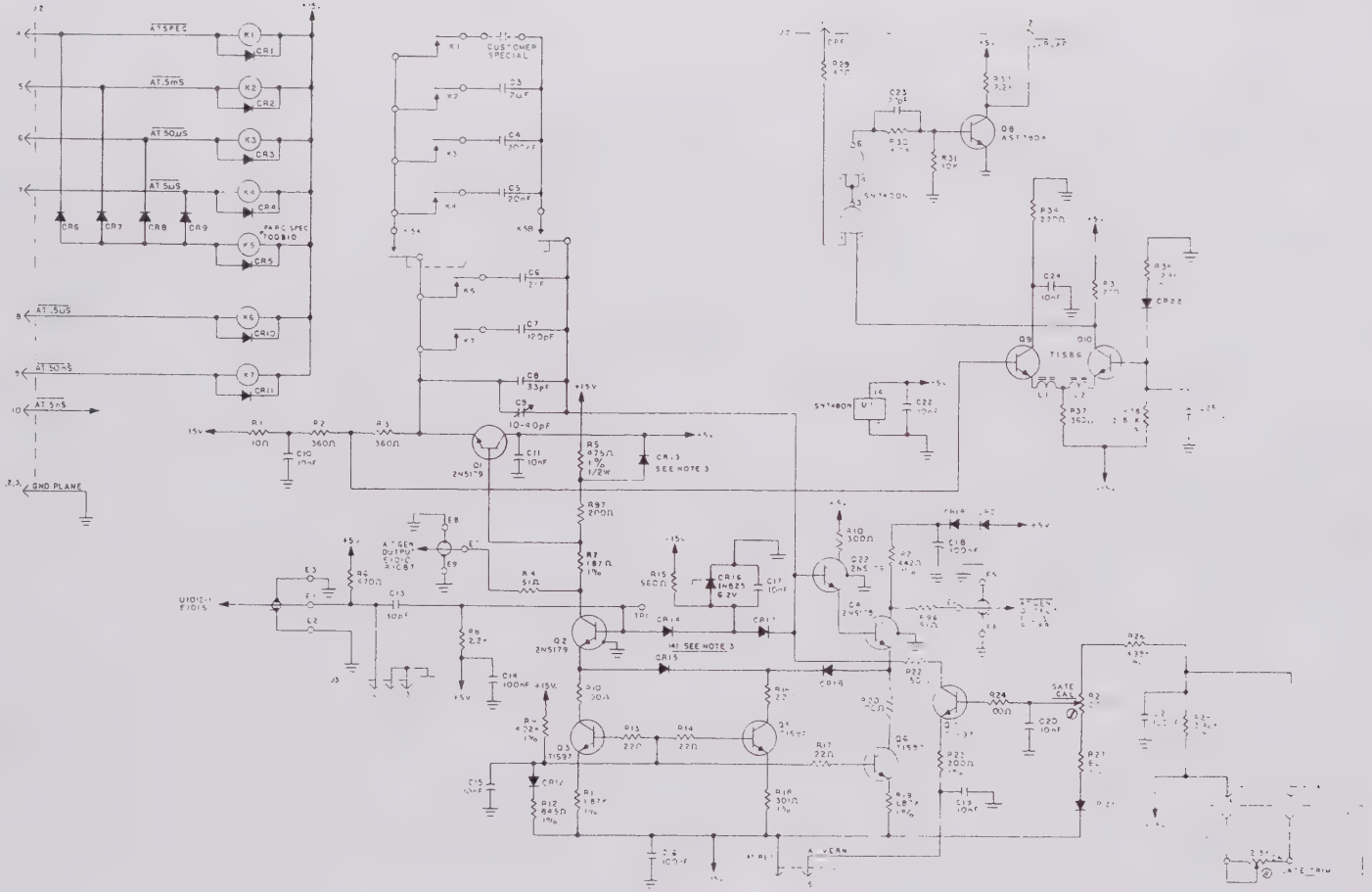
SAMPLING BOARD PARTS LOCATION DIAGRAM


INTEGRATOR SWITCH LOGIC
NANOSECOND GATE GENERATOR
TRIGGER LOGIC
SAMPLING BOARD
Princeton Applied Research Corporation
COPYRIGHT © PRINCETON APPLIED RESEARCH CORP.
ALL RIGHTS RESERVED

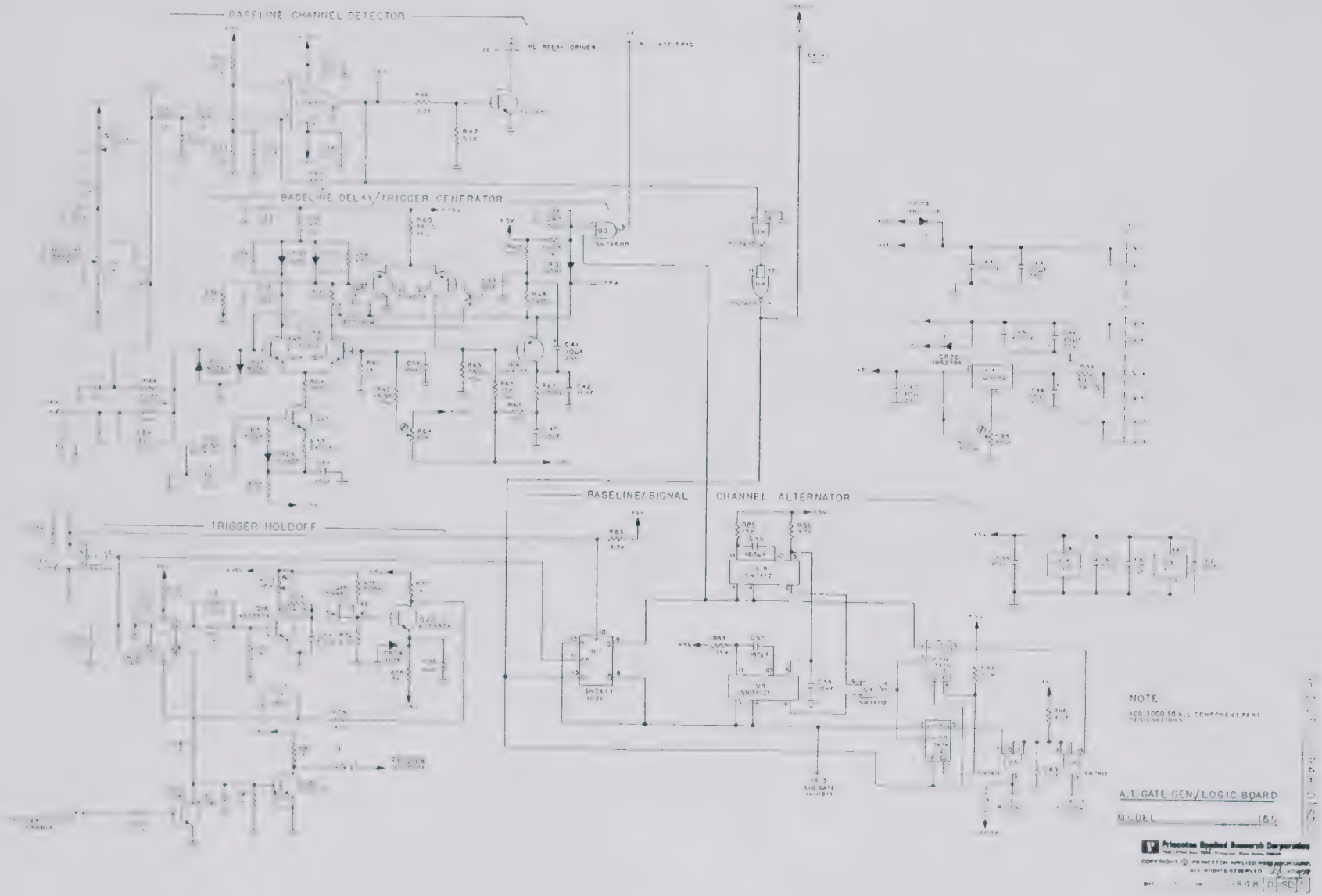


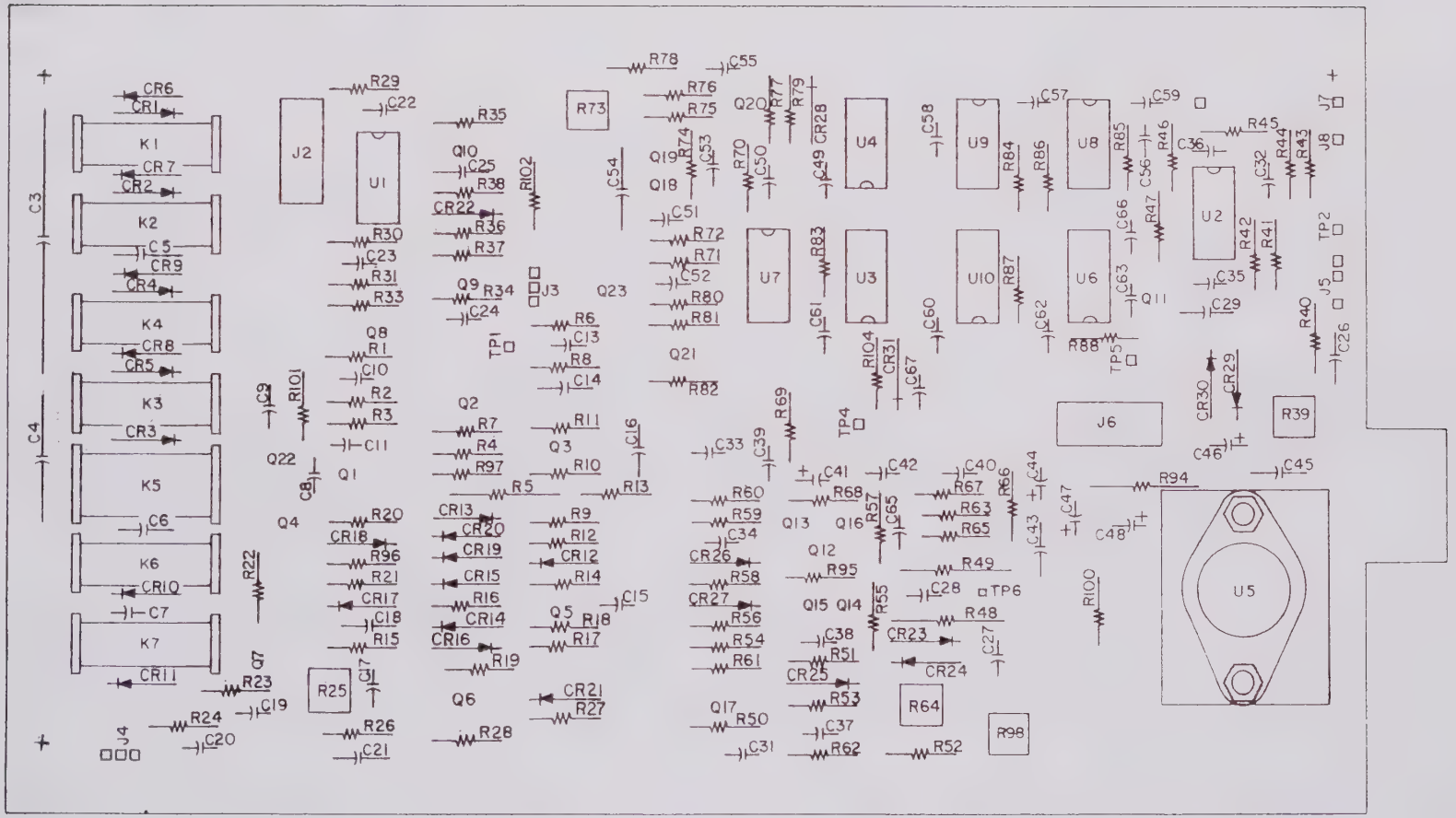
INTEGRATOR BOARD PARTS LOCATION DIAGRAM

OVERLOAD CIRCUIT
FEEDBACK SWITCH DRIVERS
INTEGRATOR BOARD
MODEL 165
Princeton Applied Research Corporation



Princeton Applied Research Corporation
COPYRIGHT © PRINCETON APPLIED RESEARCH CORP
ALL RIGHTS RESERVED


BASELINE CHANNEL DETECTOR
BASELINE DELAY/TRIGGER GENERATOR
TRIGGER HOLDOFF
BASELINE/SIGNAL CHANNEL ALTERNATOR
NOTE
A.1 GATE GEN/LOGIC BOARD
MODEL 164
Princeton Applied Research Corporation



A.T. GATE GEN./LOGIC BOARD PARTS LOCATION DIAGRAM

15328-A-MNL-A 4200-0080

EG&G
PRINCETON APPLIED RESEARCH
P. O. BOX 2565 • PRINCETON, NJ 08540, U.S.A. • 609/452-2111 • TELEX: 843409

www.manualsplus.com
1014057